PUBLIC SAFETY COMMUNICATION SERVICES REQUIREMENT AND THEIR APPLICATIONS IN THE TURKISH GEOGRAPHIC STRUCTURE

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ABSTRACT

PUBLIC SAFETY COMMUNICATION SERVICES REQUIREMENT AND THEIR APPLICATIONS IN THE TURKISH GEOGRAPHIC STRUCTURE

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Türkiye is a country which may face with many natural and social disasters due to the geography surrounding it. In this context, fast and effectual intrusion to the disasters is vital for the comfort and prosperity of the country. Certainly, such an intrusion demands a widespread, advanced, and cost-effective communications system which provides interoperability among different foundations like army, police, civil defence, fire brigade, ambulance, and some civil society organizations.

At this point two systems come to front as the solution: APCO25 widely used in North America and TETRA widely used in Europe.

In the studies of this thesis the aforementioned two systems are compared with respect to their technical specifications especially the coverage areas; the results obtained are investigated in detail; and finally, by depending on a technology selection model in the literature, one of the systems is proposed as a solution.

The coverage analyses are implemented using the computer program National Spectrum Management System (NSMS) developed by TÜBİTAK for the base stations of two alternative systems placed on several certain locations in Ankara province and the results are submitted in a visual manner. Analyses are divided into two classes to compare the coverage area of a single base station and the total coverage area of a group of base stations.

Keywords: Public Safety and Emergency Communications, Private Mobile Radios, Public Access Mobile Radios, APCO25, TETRA, Coverage Analysis

ÖZ

KAMU GÜVENLİĞİ HABERLEŞME SİSTEMLERİNE OLAN İHTİYAÇ VE TÜRKİYE'NİN COĞRAFİ YAPISINDAKİ UYGULAMALAR

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Türkiye, içinde bulunduğu coğrafya itibarı ile doğal ve sosyal kaynaklı pek çok geniş çaplı felakete uğrayabilecek konumdaki bir ülkedir. Bu bakımdan başına gelebilecek felaketlere hızlı ve etkin bir şekilde müdahale edebilmesi ülkenin refahı ve huzuru açısından hayati öneme sahiptir. Bu tip bir müdahalenin yapılabilmesi için de şüphesiz ki, silahlı kuvetler, polis, sivil savunma, itfaiye, ambulans ve bazı sivil toplum kuruluşları gibi farklı organizasyonların entegre olabilmesini saglayan, yaygın, gelişmiş ve maliyet-etkin bir haberleşme sistemine ihtiyaç duyulmaktadır.

Bu noktada çözüm olarak iki sistem karşımıza çıkmaktadır: Yaygın olarak Kuzey Amerika'da kullanılan APCO25 ve Avrupa'da yaygın olan TETRA.

Bu tezin kapsamında yapılan çalışmalarda, yukarıda adı geçen iki sistem teknik özellikler bakımdan özellikle de kaplama alanları bakımından karşılaştırılmış; ulaşılan sonuçlar detaylı olarak irdelenmiş ve neticede, literatürdeki bir teknoloji seçim modeline dayanarak, alternatif sistemlerden biri çözüm olarak önerilmiştir.

Kaplama analizleri TÜBİTAK'ın geliştirmiş olduğu Milli Frekans Yönetim Sistemi (MFYS) yazılımı kullanılmak suretiyle Ankara ili üzerinde belli bölgelere yerleştirilen iki alternatif sistemin baz istasyonları için yapılmış ve sonuçları görsel olarak sunulmuştur. Analizler istasyonların tek tek ve toplu halde kaplama alanlarının karşılaştırılması şeklinde iki grupta gerçekleştirilmiştir.

Anahtar Kelimeler: Kamu Güvenliği ve Acil Durum Haberleşmesi, Özel Telsiz Sistemleri, Ortak Kullanımlı Telsiz Sistemleri, APCO25, TETRA, Kaplama Analizi

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Above all, I want to express my deep and sincere gratitude to my supervisor Assoc. Prof. Halil T. EYYUBOĞLU from Çankaya University, Ankara / Türkiye. His wide knowledge and his logical way of thinking have been of great value for me. His understanding, encouraging and personal guidance have provided a good basis for my thesis.

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LIST OF ABBREVIATIONS

ACELP	Algebraic Code-book Excited Linear Predictive
ACK	Acknowledged
AES	Advanced Encryption Standard
AI	Air Interface
ANSI	American National Standards Institute
APCO	The Associaton of Public-Safety Communications Officials
BCH	Bose, Ray-Chaudhuri, Hocquenghem
BRA	Basic Rate Access
BS	Base Station
C4FM	Continuous 4 level Frequency Modulation
CAI	Common Air Interface
CEPT	The Conference of European Postal and Telecommunications Administrations
COTS	Commercial Off The Shelf
CQPSK	Compatible Quadrature Phase-Shift Keying
CSSI	Console Sub-System Interface
DES	Data Encryption Standard
DIMRS	Digital Integrated Mobile Radio System
DMI	Direct Mode Interface
DMO	Direct Mode Operation
DQPSK	Differential Quadrature Phase-Shift Keying
DTED	Digital Terrain Elevation Data
EDACS	Enhanced Digital Access Communications System
EMTEL	Emergency Telecommunications
ETSI	European Telecommunications Standards Institute
FDMA	Frequency Division Multiple Access
FHMA	Frequency Hopping Multiple Access

FIR	Finite Impulse Response
FS	Fixed Station
FSK	Frequency Shift Keying
GETS	Government Emergency Telecommunications System
GSM	Global System for Mobile Communications
GUI	Graphical User Interface
HF	High Frequency
IDRA	Integrated Dispatch Radio
IEEE	Institute of Electrical and Electronics Engineers
IMBE	Improved Multi-Band Excitation
IOP	Interoperability
ISDN	Integrated Services Digital Network
ISI	Inter-System Interface
ISSI	Inter Sub-System Interface
ITU	International Telecommunication Union
LSI	Line Station Interface
MCCH	Main Control Channel
MS	Mobile Station
NASTD	National Association of State Telecommunications Directors
NATO	North Atlantic Treaty Organization
NCS	National Communications System
NMI	Network Management Interface
NSMS	National Spectrum Management System
OSPs	Outbound Signalling Packets
OTAR	Over The Air Re-keying
PABX	Private Automatic Branch Exchange
PAMR	Public Access Mobile Radio
PDO	Packet Data Optimized
PEI	Peripheral Equipment Interface
PMR	Private Mobile Radio
PRA	Primary Rate Access
PSTN	Public Switched Telephone Network
PTT	Push-to-Talk
QAM	Quadrature Amplitude Modulation

RF	Radio Frequency
RFSS	RF Sub-System
SMS	Short Message Service
SNA	Systems Network Architecture
SU	Subscriber Unit
TCH	Traffic Channel
TCP/IP	Transmission Control Protocol / Internet Protocol
TDMA	Time Division Multiple Access
TETRA	Terrestrial Trunked Radio
UHF	Ultra High Frequency
VHF	Very High Frequency
VoIP	Voice over Internet Protocol
WGID	Working Group Identification
WUID	Working Unit Identification

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CHAPTER 1

INTRODUCTION

There are several Emergency Management Agencies all over the world that come in action during the emergency. The sole purpose of Emergency Management is to respond to a disaster and provide aid accordingly. The responsibility of these agencies is huge and the emergency communications is one of the most crucial parts of this responsibility.

During a disaster, telecommunications networks can support many important functions ranging from alerting local populations, to coordinating emergency response activities among government and non-government agencies, to enabling the continuity of government functions and business transactions [21]. The GETS (Government Emergency Telecommunications System) program in the United States represents one example of this emergency telecommunications role. GETS is an emergency telephone service offered by the National Communications System (NCS), within the Department of Homeland Security, and is designed to provide all levels of government, industry, and non-governmental organizations with emergency access and priority processing in both the local and long distance segments of the Public Switched Telephone Network (PSTN).

Public safety communications generally refers to small scale incidents where people use a telephone to contact emergency services for help. Today, this simple function is becoming complicated by recent developments such as mobile phones and VoIP, but its essential design remains the same and is based on a single, widely known emergency number (911 or 112) available in most major urban centres in the United States. Although there are important and essential distinctions are available between the localized incidents and widespread disasters, the generic term "emergency communications" is used to refer to both kinds of programs. For instance, the European Telecommunications Standards Institute (ETSI) under its Emergency Telecommunications (EMTEL) program takes a comprehensive approach by its scope of activities:

- Provisioning of telecommunications services in emergency, this may range from a narrow perspective to a very broad perspective.
- Provisioning telecommunications needs of police forces, fire fighting units, ambulance services and other health and medical services, as well as civil defence services.
- Dissemination of information to the public, in particular in hazardous and disaster situations.

1.1 Current Situation In Türkiye

Emergency Management General Directorship forms the public safety communications strategy of Türkiye. Lots of urban and rural Emergency Management units are available in our country although there is a single management authority according to the laws. Therefore, many organizations may interfere before and after an event. For example, in a forest fire, Forest Staff – Fire Teams, Gendarme and Ambulance take place inevitably. All of these units have to work in coordination. However, as also the case in Türkiye, the communication infrastructures of these units can be different.

At the disasters such as earthquake, landslide, fire, nuclear and chemical accidents and migrations affecting the country security, emergency management should be implemented effectively. Turkish Emergency Management General Directorship is established to take the precautions before the emergency events happen; to carry on the search and rescue activities at the instant of the events; and to execute the relief activities after the events. The tasks of the Turkish Emergency Management General Directorship are summarized below [20].

- Providing the establishment of emergency management centers at the governmental associations and organizations

  - To carry on the emergency management effectively
  - To ensure the coordination among these centers.
- Monitoring and evaluation of
  - Precautions taken by related associations and organizations to reduce the losses and the events causing emergency
  - Preparation of short and long term plans
  - Formation of data banks
- Carrying out the coordination of arranging the usage of the ground, sea, and air vehicles which belong to the public and the private sector at the emergency.
- Carrying out the coordination of
  - Encouraging the volunteers
  - Protection and delivery of aid materials

In addition to these responsibilities the following activities are also maintained in the directorship.

- Operating the communication center 365 days / 24 hours
- Watching the Anadolu Agency news via on-line connection
- Evaluation of
  - Periodical earthquake reports from Boğaziçi University Kandilli Observatory and Ministry of Public Works, Disaster Staff General Directorship
  - Periodical meteorological forecast reports from Meteorological Staff General Directorship

Some of the projects governed by the Emergency Management General Directorship are given below.

- Prime Ministry Crisis Management and Government Operations and Communications, Electronics, Information Systems Project: With this project it is aimed to provide uninterrupted communication at the disaster and crisis situations. However, this project is especially for the earthquake disaster.
- İstanbul Seismic Mitigation and Emergency Preparedness Project: The solution of the communication problems at the disaster regions firstly becomes an isssue with this project. Project is composed of four components:

Preperation, Damage Reduction, Intervention, and Rehabilitation. The establishment and the development of the emergency communication systems is a part of the preperation component. For this reason, Nippon Telegraph and Telephone East Corporation firm is employed for the preparation of a feasibility report and and an emergency communication system model for İstanbul.

Although Emergency Management General Directorship is responsible for coordinating all activities related to emergency, a common communication infrastructure has not been achived yet. Some organizations like Turkish Army Forces and Gendarme have already developed their own network. But some other organizations are still using analog technology. Therefore, they are still having problems in frequency, coverage area, transmitting data, etc.

Currently, although the organizations use the VHF / UHF technologies, they have their own infrastructures such as base stations, repeaters. Public safety and emergency staff use Türk Telekom and GSM infrastructures for cross communications.

1.2 Problem Statement

Public safety organizations have suffered considerably from a lack of cross-agency radio communications for the recent years. Although there are many other problems, the main difficulties are sharing information among different organizations and wide area coverage requirement. In many cases, public safety agencies are not able to share vital information due to the lack of interoperability or common communication infrastructure. Currently, all agencies have their own communications systems, which are mostly conventional radios, based on different technology. On the other hand, these agencies are required to communicate each other in mainly voice and sometimes data form to cope with a natural disaster, a big accident, or a terrorist attack. Voice communications between public safety practitioners and their supervisors, dispatchers, members of the task force, etc., require immediate and high-quality response, and must meet much higher performance demands than those required by commercial users of wireless communications. Data communications can provide practitioners with maps, floor plans, video scenes, etc. Commanders, supervisors, medical staff, etc., can make wise decisions and do their jobs effectively with the data coming from the field personnel, and vice versa.

Although there are many reasons why public safety agencies are not able to communicate to each other, primarily there are three reasons.

First, frequency bands differ from one to another agency. There are four distinctive frequency bands that can be used primarily by public safety and most radio manufactures only produce single band radios. Therefore, an agency with a VHF low radio system will usually only be able to communicate with another agency using radios in the same range (providing common frequencies have been pre-programmed in the radios).

The four primary public safety bands are:

1. VHF Low, which operates in the 30 - 40 MHz range
2. VHF High, which operates in the 152 - 162 MHz range;
3. UHF, which encompasses 406-512 MHz;
4. 800 MHz operations.

Generally, many people believe that public safety staff can talk to each other seamlessly during a mutual aid event. The reality is different that what people believe. In many cases, a police department and fire department from the same municipality are on different radio systems and often cannot communicate with each other via radio during the event.

The second primary reason, even when agencies are using radio systems in the same frequency range, some radio manufacturers are not compatible with others. As a result of this incompatibility agencies are unable to communicate. Therefore, a bridging device or a gateway is needed to connect disparate radio systems that are operating in the same frequency range.

Finally, when all the technical barriers are removed and the radios are able to communicate with one another, if agencies have not adopted a common language for all first responders in the area, there may still exist a failure to communicate at the human level, as proprietary radio codes can make a very busy scene even more confusing.

1999 Marmara Earthquake was one of the clearest examples showing the requirement of the reliable and interoperable public safety communications. The declarations at Kocaeli 99 Meeting, on which the situation after the Marmara Earthquake was evaluated, came to the conclusion that the insufficiencies in disaster management before and after an earthquake could be collected in four main groups. Some of them were due to governmental reasons and the others were social reasons. The lack of coordination was the most appearent governmental insufficiency. This insufficiency pointed out the strong requirement of communication between public safety and the emergency organizations. Right after the eathquake took placed the connection between the region and the other parts of the country was cut off. At the first step this problem was overcome by employing the HF radio systems of military forces, afterwards GSM systems were in place, and finally the mobile Türk Telekom systems deployed in the region. However, the main problem came out to be at the communication of the organizations providing the service of search and rescue, and service of safety and emergency. Certainly, all people and related organizations such as Turkish Army Forces, police, hospitals, various search and rescue units, and lots of other foundations made great effort to help the region. All of these organizations had their own communication systems. For cross communications among those, PSTN network governed by Türk Telekom and GSM services provided by some companies were the only operational infrastructures. However, their infrastructures had been damaged considerably by the earthquake.

Altough mobile GSM base stations were in place right after, they were far away to cope with the traffic requirement. Some of the reasons why GSM systems could not cope with the expectations are listed below [5].

- *Fast call set up:* Takes many seconds in GSM.
- *Group call:* Not available in GSM. Only one mobile phone can be accessed at a time.
- *Large area coverage:* Not applicable in GSM. Small cells, population coverage.

- *Push-To-Talk capability:* Not available in all cellular phones. One has to dial the number.
- *High speed data/video transmission:* Low speed data transmission in GSM.
- *Mobile-to-Mobile connection:* Not available in GSM. Need for base station.

In the USA, to determine the public safety communications capability of the cellular phones having push-to-talk (PTT) feature, the products of three different USA carriers (Nextel, Sprint, and Verizon) are tested and the following results are reached [9]:

- Incompatibility of different technologies among different providers which prevent users on different networks from communicating
- Noticeable latency for call setup times on Verizon and Sprint networks:

Table 1-1 Measured delay performance of PTT services.

	Call Set Up Time (seconds)			Initial Voice Delay (seconds)			Intra-call Voice Delay (seconds)		
	Min	Av	Max	Min	Av	Max	Min	Av	Max
Nextel	0.81	0.92	1.10	1.69	1.82	1.97	0.40	0.58	0.85
Verizon Wireless	3.35	6.32	8.93	7.69	9.18	11.06	1.28	1.54	1.82
Sprint PCS	2.25	4.34	6.91	8.09	10.16	15.38	0.96	1.15	1.34

- Lack of priority access during network congestion (Only Nextel offers first responders special features available only for the public safety user)
- Lack of security or communications privacy on commertial networks
- Inability to receive PTT calls/alerts while on regular voice call
- No roaming agreements among carriers to expand coverage areas
- Inability to rapidly set up talkgroups in the field
- Inability to see call attempts from other groups after completion of a PTT call

Evaluation summary of exsisting communication capabilities:

- No or limited interoperability
- Only voice capability

- Limited coverage area
- Frequency allocation problems
- No prioritizations

As a result, the problems and insufficiencies mentioned in this section denote that Türkiye needs a new, widespread emergency communications infrastructure to cope with the disasters, which may happen in the future.

1.3 Alternative Solutions

The main part of the thesis is devoted to the investigation of the problem stated in the previous section. As the solution, two standards regulating whole radio networks come to front: APCO25 and TETRA. The detailed description and comparison of these standards are in the scope of the thesis.

1.4 Scope of the Thesis

In CHAPTER 2 the main requirements of public safety and emergency communications systems are discussed. The technical characteristics of APCO25 and TETRA systems, which are the alternative solutions to public safety and emergency communications problem of Türkiye, are given in CHAPTER 3. The coverage analysis results for the APCO25 and TETRA base stations placed several locations in Ankara province are shown in CHAPTER 4. Finally, the alternatives are evaluated and one of them is proposed as a solution in CHAPTER 5.

CHAPTER 2

STATEMENT OF REQUIREMENTS

The key requirements of an emergency communication system can be extracted from a realistic explosion scenario. This scenario focuses on the command and control, asset status and tracking, and major communications interoperability aspects of an incident involving first responders [13].

1. A large explosion occurs at a chemical fabric of Ankara. The potential dangers are the hazardous chemical leakage and toxic smoke from the chemicals burning.

2. Firstly the police arrive at the scene assessing the situation. After briefly surveying the area, the police team starts radio communications and begins to send/receive information. The information can be voice or data.

3. The information sent by the police is shown on the display in front of the emergency manager at the same time.

4. The fire branch monitors the status, location, and current duties of the fire fighters on its command screen, and assigns more fighters if necessary. The same situation is repeated for the medical service branch.

5. After completing all of the pre-defined tasks for this particular type of incident, the police begin coordinating with the medical service and fire fighters. The fire branch informs emergency manager that the incident is too large to be handled by the available assets. After evaluating the situation, the manager decides for the dispatch of more fire units.

6. The medical branch sets up a treatment area and begins to direct the resources available to identify and handle casualties.

7. The fire branch is notified of an emergency on its command screen as one of the firefighters in the field has a passive sensor triggered by the detection of a hazardous chemical. The branch designates this area as a Danger Zone, which alerts any personnel entering the designated area to its status.

8. Because of the potential for the release of hazardous chemicals, the emergency manager directs all available hazardous materials teams to the location.

9. The manager notes the perimeter of the chemical leakage changes and starts the process warning call that is sent to all fixed and cellular telephones inside the secondary perimeter. This call instructs the people inside the perimeter to find shelter in the area quickly and to close off all outside ventilation.

10. The traffic branch is directed to coordinate with the Department of Transportation to configure traffic management assets, such as traffic lights and electronic signs, to divert traffic away from the incident.

11. The emergency manager begins to coordinate with the public utilities and other private organizations for the appropriate responses, such as shutting down gas lines to the area and dispatching electrical crews to handle situations, such as downed power lines.

12. Upon further investigation by police and fire assets, it is determined that this explosion was not an accident. Then manager directs police to treat the area as a crime scene, and assigns detectives to begin an investigation of the crime scene in coordination with fire investigators.

The scenario given above shows that, in an emergency event, many unexpected situations may happen and many connections may be established among different responders. The key requirements of an emergency communication system extracted from the scenario can be listed as the followings.

1. *Interoperability* between different organizations such as police, medical services, fire fighters, traffic polices, etc. is the first striking requirement. General definition of interoperability is responders from different agencies being able to talk to each other [16]. Interoperability is a hard problem because of the incompatible and aging communications equipment, limited and fragmented funding, limited and fragmented planning and coordination, limited and fragmented radio spectrum, and limited equipment standards (Figure 2-1). Türkiye is one of the countries suffering from the lack of interoperability due to the reasons explained above.

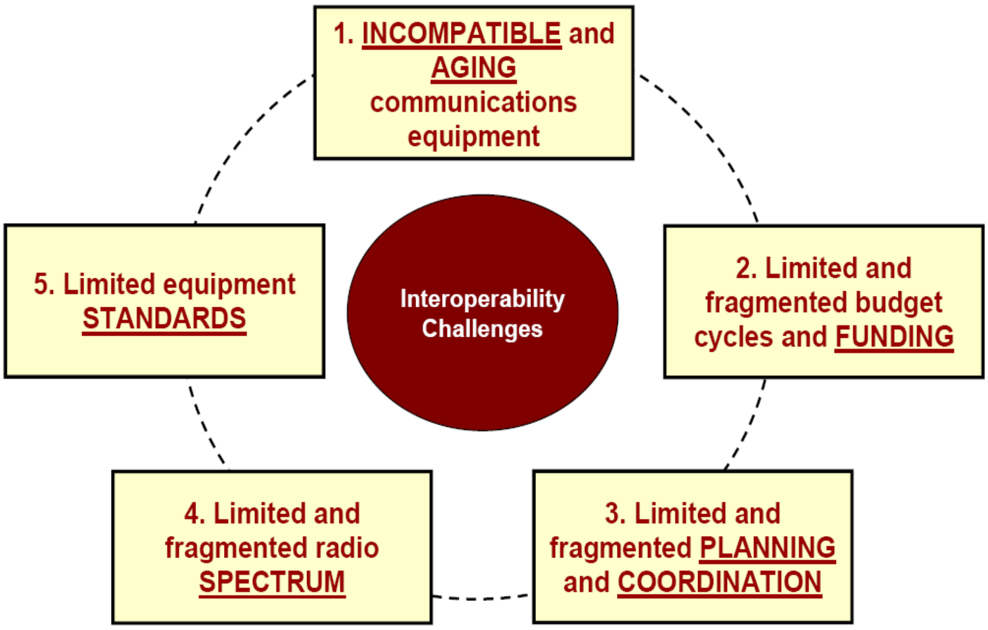

Figure 2-1 Interoperability challenges [13].

It should be remembered here that there are three basic interoperability solutions that cost nothing or very little:

- Pre-program all mobile and portable radios with national interoperability channels in all frequencies (usually no infrastructure involved or required)
- Share radio frequencies with neighbors on compatible radio systems (conventional or trunked radio systems); and
- Drop most radio codes and adopt a common language communications for day-to-day transmissions. Remember, in an emergency, an agency will

"play like they practice". Encourage mutual aid regularly using radio communications.

2. *Reliability* is another important requirement. For an emergency communications system, reliability can be defined such that a network should not stop functioning even in hard situations such as an explosion, an earthquake, a big fire, etc. The other explanation of reliability is that the information should be transmitted with no error. Since the emergency communications is very critical and any wrong information may cause larger disasters, reliability of a communication system has vital importance. Considering the scenario, assume that the perimeter of the leakage is sent errorneously and as a result of this, the precautions taken by the traffic branch does not cover the leakage area. It is not hard at all to estimate the extents of the disaster arising from this small fault.

3. *Capacity* of a communication network should be large enough to send/receive large amount of voice signal and data at the same time interval and to connect large number of responders at the same time. Although for many years voice communications has appeared critical, because of advances in technology, public safety operations are increasingly becoming dependent on the sharing of data, such as images and video. As a result of this, the capacity requirement has increased considerably.

4. Emergency communications systems require *expandability* to be able to provide the peak traffic during a disaster. In normal time, operation may not require high capacity, but in case of emergency, many users may use the system at the same time.

5. *Operability* is a very critical issue of emergency communications. Two types of operations are considered: Centralized and decentralized. Centralized communications is controlled from a command center and the responders communicate each other by the rules stated by the commander. Decentralized communications is not controlled and every responder can communicate each other without any restriction. In emergency, especially the centralized communications becomes important.

6. *Availability* is an indispensible requirement of an emergency communications network. Availability can be defined, as a measure of the coverage area under which all of the responders are connected no matter how remote or isolated.

7. Emergency communications has a requirement of high level of *security*. Especially the army forces and security department require high level of security or encrypted communications to protect their operations.

8. *Compatibility* is one of the most important feature of an emergency communication system for feasibility, low cost and the usage of available systems. In addition to this, an emergency communication system should be compatible with the global telecommunications standards such as ITU, ETSI, IEEE, etc.

As a summary the key requirements of an emergency communications system can be given as:

- Interoperability
- Reliability
- Capacity
- Expandability
- Operability
- Availability (or Coverage Capability)
- Security
- Compatibility

The remaining part of the thesis is devoted for the investigation of the public safety communications systems applicable in Türkiye by taking into account the requirements explained in this chapter.

CHAPTER 3

EXAMINATION ON ALTERNATIVE SOLUTIONS

Before examining the alternative solutions for the public safety and emergency communications, it will be beneficial to discuss the radio systems briefly. The importance of the radio communications, depending on the sending and receiving of electromagnetic signals via antennas, increases day by day. In addition to provision of individual communications requirements, the mobile communication systems also have a very important role in achievement of public safety.

In Figure 3-1, technology migration in public safety communications is shown. As seen in the figure, the complexity and the capabilities of the technology increases from past to future.

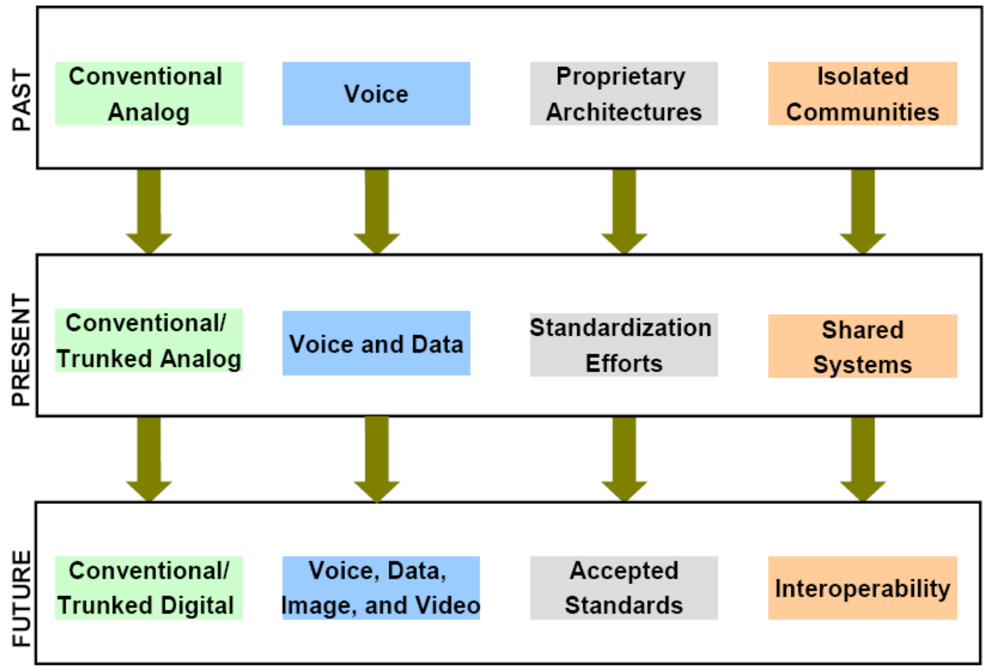

Figure 3-1 Technology migration in public safety communications [13].

In the radio communications the message (voice or data) is sent via an electromagnetic wave serving as a carrier. This wave is sent by a transmitter with a frequency and taken by a receiver via an antenna. The message taken by the receiver is sent to a speaker or a peripheral such as a printer or a data terminal.

Another important point of the radio communications is that the operations of the radios change by the usage of the same or different frequencies at sending and receiving ends. If the radios use the same frequency at sending and receiving, the operation is called simplex otherwise it is called as duplex. There are two types of duplex operations: Full and half. In the full duplex operation, sending and receiving can happen simultaneously.

The radio communications systems can be classified according to the operational features, transmission types, and utilization purposes.

3.1 Classification by Operational Features

Radio systems may be grouped as *conventional* and *trunked*, according to their operational features.

3.1.1 Conventional Systems

Conventional systems are the systems where all users in a net wait in one channel and send/receive messages over the same channel. There is no channel switching logic or control / traffic channel distinction; all channels are used for both control signaling and communication traffic.

The communication distance of a radio is limited by the output power and the geographical and climatic conditions. Adding a repeater can increase this distance. These kinds of systems are called *systems with single relay*. To communicate in a wider area, more relays are connected via wired or wireless links. Such systems are called as *wide area coverage systems*.

3.1.2 Trunked Systems

In the conventional systems the channels are used continuously. The channels can be used more efficiently by assigning them to the users with a time-sharing basis via a controller. This solution is called trunking. In a conventional radio system, the radio users control the operation of the system, whereas in a trunked system the management of system operation is automatic.

According to Figure 3-2 trunked communication systems begins to support more radio users than conventional radio systems when three or more RF channels are used [22]. Because trunking systems support more radio users than conventional systems, many organizations support the deployment of trunking systems.

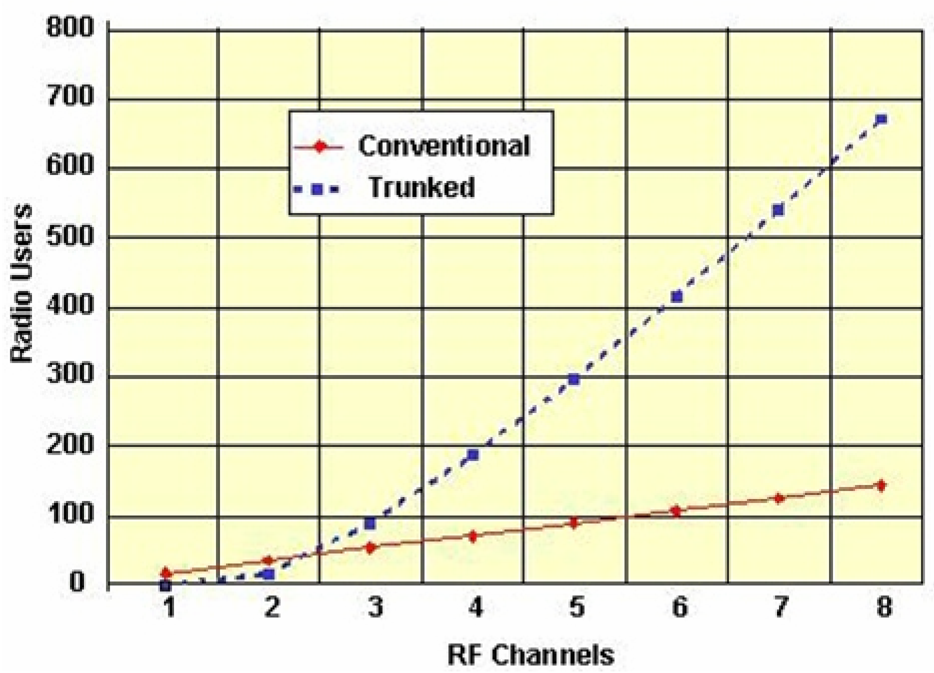

Figure 3-2 Conventional and Trunked radio user loading comparison.

Trunked radio systems can be thought as a conventional radio system having more than one channel. One of the channels, called as *control channel*, is used for the signaling between the system and the channels. The other channels are used for voice or data communications and called as *traffic channel*.

Radios access the system via signaling at the control channel. The communication requirement is evaluated by the system and declared to the other radios by the control channel. The performance of the radio system is considerably determined by the signaling. The signaling method used should coordinate the radios and allow the requests to be understood in the shortest time. In the following table the trunking solutions to the conventional systems' problems are given.

Table 3-1 Conventional radio systems' problems solved by trunking.

Problem	Solution
Contention	All call requests are handled on the control channel for immediate call processing or in order of queue priority if the system is busy.
Manual Switching of Channels	Automatic cell handover takes away the need for manual channel selection
Inefficient Channel Utilization	The automatic and dynamic assignment of a small number of communication channels shared amongst a relatively large number of users ensures an equal grade of service for all radio users on the system.
Lack of Privacy	The dynamic and random allocation of channels makes it more difficult for a casual eavesdropper to monitor conversations.
Radio User Abuse	Abuse is minimized as the identity of all radio users and the time and duration of messages are known and can therefore be easily traced to the abuser.

3.2 Classification by Transmission Type

Radio systems may be grouped as *Analog* and *Digital* radio systems, according to their transmission types.

3.2.1 Analog Radio Systems

Analog radio systems continuously transmit radio waves that are usually modulated by a voice signal [7]. A typical analog voice radio consists of a transmitter and receiver (Figure 3-3).

Figure 3-3 Block diagram of a typical analog radio system.

An analog system may also carry data. However, the data, which are in digital form of binary digits, or bits (i.e., ones and zeros), must first be converted to an analog signal. A modem (modulate/demodulate unit) is used to convert the ones and zeros into two analog tones representing either a one or a zero. When the analog data arrive at the receiver, they are converted back to digital form again using another modem.

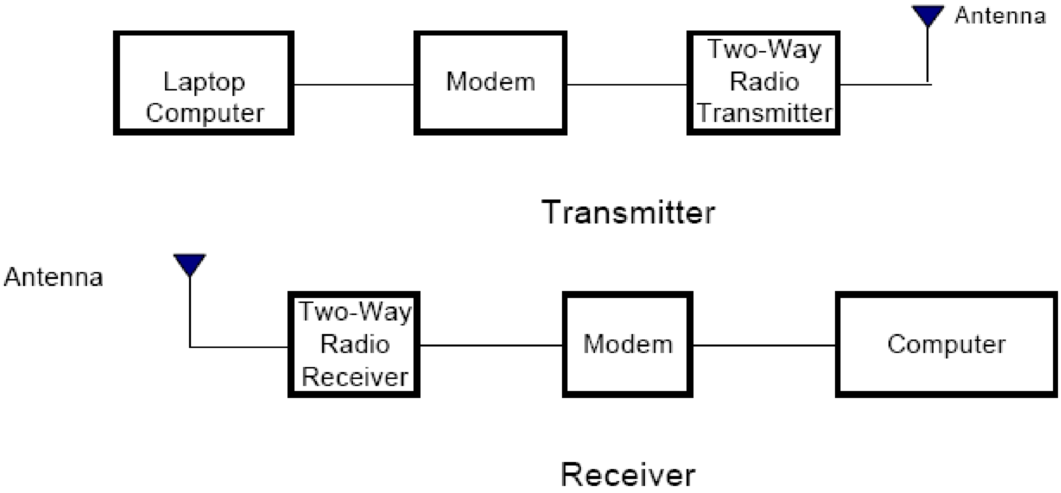

Figure 3-4 Block diagram of an analog radio data communication.

3.2.2 Digital Radio Systems

A digital radio system transmits data directly, by digitally modulating a carrier. One simple method of modulation is to change the carrier frequency by shifting it different amounts for each type of bit (This is called frequency shift keying, or FSK). The receiver then receives the signal as a zero or as a one and recreates the original signal. A simplified digital radio is shown in Figure 3-5. The ones and zeros are detected and regenerated at a receiver for use in a computer.

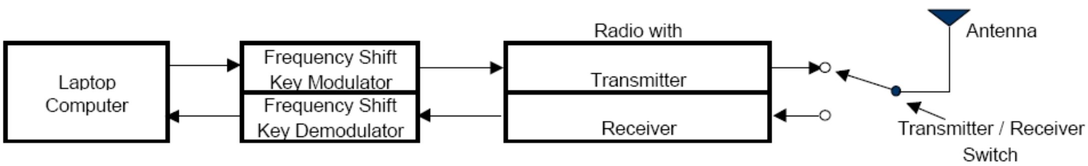

Figure 3-5 Block diagram of a typical digital radio system.

Voice transmissions may be sent over digital radio systems by sampling voice characteristics and then changing the sampled information to ones and zeros to modulate the carrier. This is done using a circuit called a voice coder, or *vocoder*. At the receiver, the process is reversed to convert the digital voice samples back into analog voice. A diagram of a typical digital voice radio system is shown in Figure 3-6.

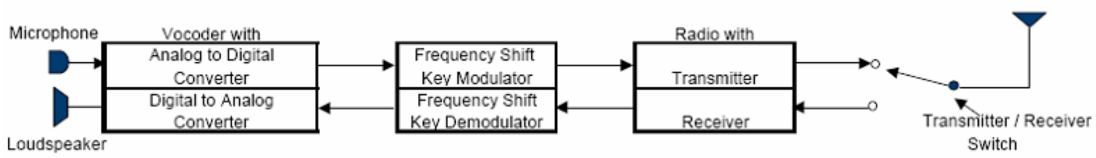

Figure 3-6 Block diagram of a digital radio voice communication.

3.3 Classification by Utilization Purposes

Radio systems may be grouped as *Public Access Mobile Radio* (*PAMR*) and *Private Mobile Radio* (*PMR*) systems, according to their utilization purposes.

3.3.1 PAMR Systems

PAMR systems are the systems where more than one user group use voice channels. They are generally commercial systems and administrated by a special operator. The same operator undertakes the infrastructure responsibility. In the PAMR systems generally small user groups come together and use the system resources jointly. The user groups can be different and need not to be related.

3.3.2 PMR Systems

In contrast to PAMR networks, PMR networks are used exclusively by one organization. PMR user groups own their network of terminals and base stations. The PMR system may be restricted to a specific area, e.g., factory area or town. Users have their own channels; that is every PMR system uses a different set of frequency channels. There are a wide variety of users of PMR systems:

- Public safety: Police, fire, ambulance, mountain rescue, etc.
- Non-safety national government: Other governmental agencies, such as non-emergency health, customs, etc.

- Non-safety local government.
- Transport: Railways, buses, taxi, etc.
- Other utilities: Water, electricity, gas, and coal.

There are some basic PMR configurations, which, are commonly being used. One of the most common PMR configurations is the dispatch operation, which is shown in Figure 3-7. At least two channels are used, one for uplink and one for downlink. All terminals can receive the downlink transmissions by the dispatcher. Point to point communication is also possible. The dispatcher can only receive the messages from the mobile stations.

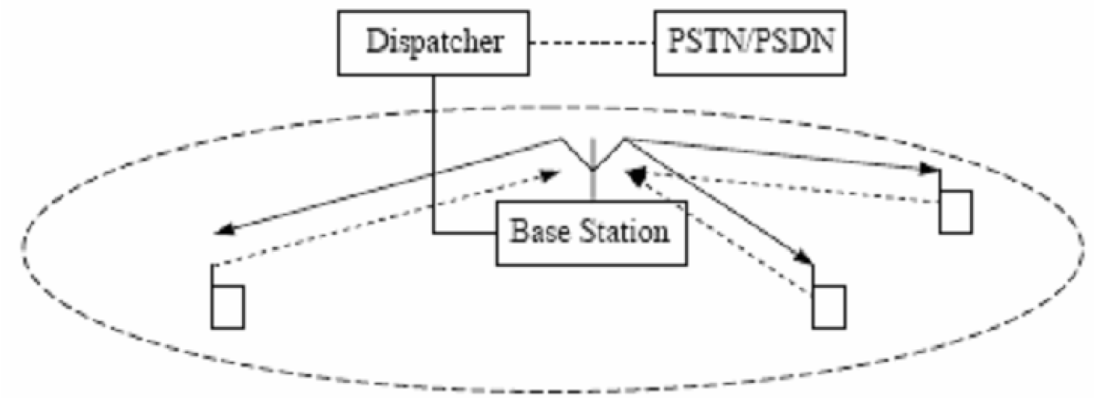

Figure 3-7 Dispatch mode configuration.

To extend the coverage area of mobile stations, a base station can be connected as a repeater. The base station retransmits the messages on the downlink. This extends the coverage area of mobile stations to that of base station. In Figure 3-8, mobile 1 can communicate with mobile 3 through the coverage area of base station.

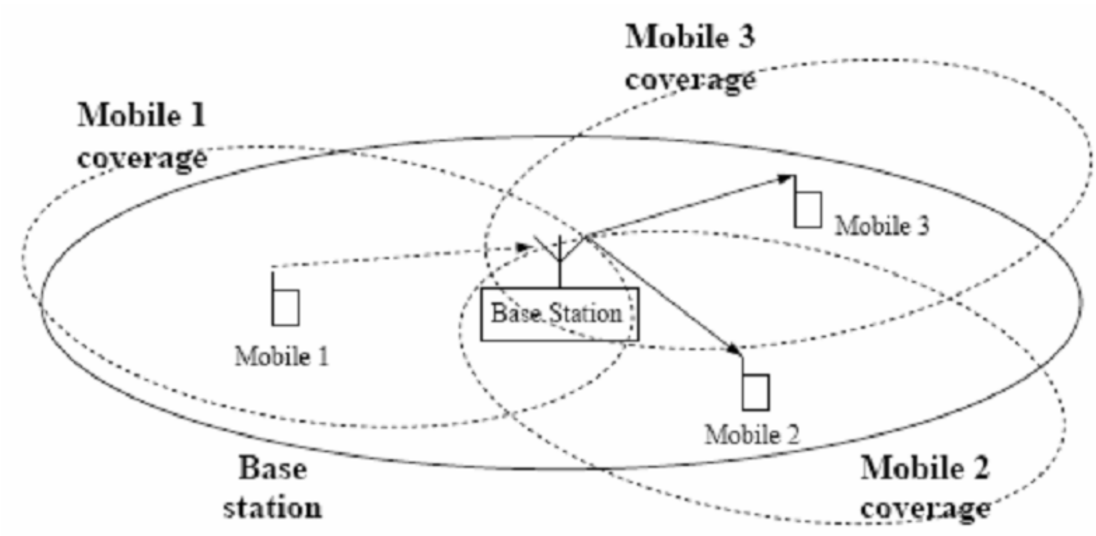

Figure 3-8 Repeater mode configuration.

In some circumstances, a single base station may not be able to cover the entire service area, i.e. due to a shadow of a building. If the uncovered area is limited to a relatively small area, a radio port can be used to provide required coverage at this area (Figure 3-9).

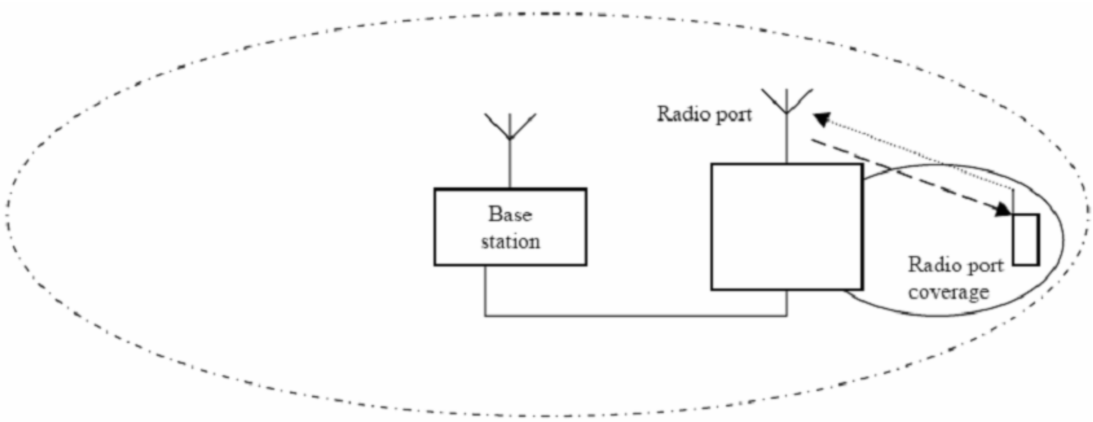

Figure 3-9 Base station – Radio port configuration.

Hand-held terminals usually have lower power than mobile terminals mounted in vehicles. Therefore mobiles have greater coverage areas than handhelds. Portable vehicle-mounted repeaters can therefore be used to provide higher coverage area to users working near to their vehicles. This mode of operation is commonly used by the emergency services (Figure 3-10).

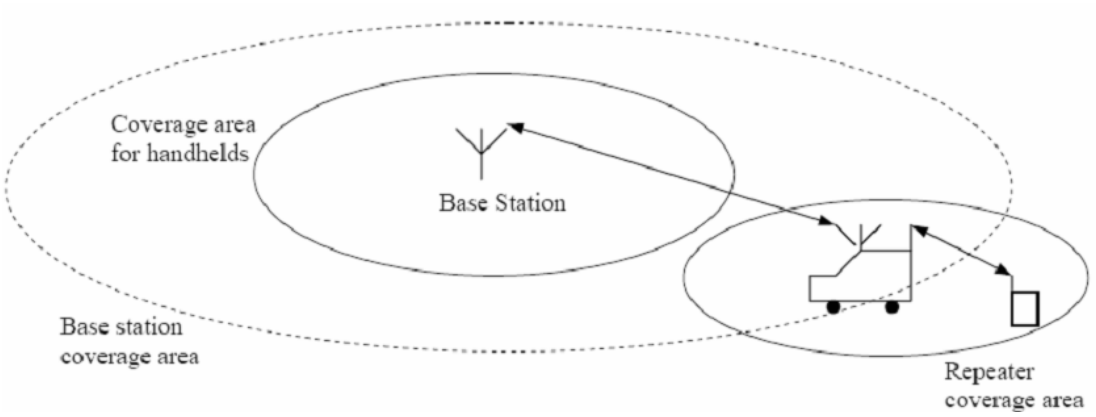

Figure 3-10 Base station – Portable vehicle mounted repeater configuration.

There are seven well-known PMR systems around the World [2]:

- *Association of Public-Safety Communications Officials – Project 25* (*APCO25*): The United States submitted Project 25 to ITU-R Working Party 8A. It includes a family of two modulation methods, C4FM and CQPSK. C4FM fits within a 12.5 kHz channel mask and uses constant-envelope modulation (i.e., does not require a linear or linearized amplifier). CQPSK fits within a 6.25 kHz channel mask but does require the use of either a linear or linearized amplifier. Both trunked and conventional (non-trunked) operation is provided for.

- *Terrestrial Trunked Radio* (*TETRA*): A number of European countries submitted TETRA to ITU-R Working Party 8A on behalf of ETSI (the European Telecommunication Standards Institute). TETRA's primary mode uses π/4 DQPSK modulation that requires a linear or linearized amplifier and fits four-slot TDMA within a 25 kHz channel mask.

- *Integrated Dispatch Radio* (*IDRA*): Japan submitted IDRA to ITU-R Working Party 8A. It also is a six-slot TDMA system using 16 QAM (16 point Quadrature Amplitude Modulation) that fit within a 25 kHz channel mask. A major difference from DIMRS is the use of a different vocoder.

- *Digital Integrated Mobile Radio System* (*DIMRS*): Canada submitted DIMRS to ITU-R Working Party 8A. It is a six-slot TDMA system using 16 QAM modulation that fits within a 25 kHz channel mask. It is designed primarily for public systems and is in use in a number of countries around the world.

Motorola Inc. is the principal manufacturer of this equipment, under the name IDEN™.

- *TETRAPOL*: France submitted Tetrapol to ITU-R Working Party 8A. It uses a constant-envelope modulation technique that fits within a 10 kHz channel mask. Systems are in use in a number of countries in Europe and around the world. EADS is the principal manufacturer of this equipment.

- *Enhanced Digital Access Communications System* (*EDACS*): L.M. Ericsson AB (with support from the Swedish Administration) submitted EDACS® Aegis™ to ITU-R Working Party 8A. It uses a constant-envelope modulation technique and has four different selectable levels of deviation and filtering that can result in the signal fitting within 25 kHz and 12.5 kHz channel masks. Systems are in use in a number of countries around the world. M/A-COM, Inc. is the principal manufacturer of this equipment.

- *Frequency Hopping Multiple Access* (*FHMA*): Israel submitted FHMA to ITU-R Working Party 8A. The system primarily makes use of frequency hopping and sectorized base station antennas to gain spectrum efficiency. The signals are error protected and when a radio is at a sector boundary, due to different frequency hop patterns between sectors, interference to and from nearby radios in the other sector is minimized.

From the market sharing view (Figure 3-11), two dominant systems, APCO25 and TETRA come to front as the solution of the public safety communications problem of Türkiye. In the following sections, detailed description of these two systems is given; and then, they are compared according to their technical specifications.

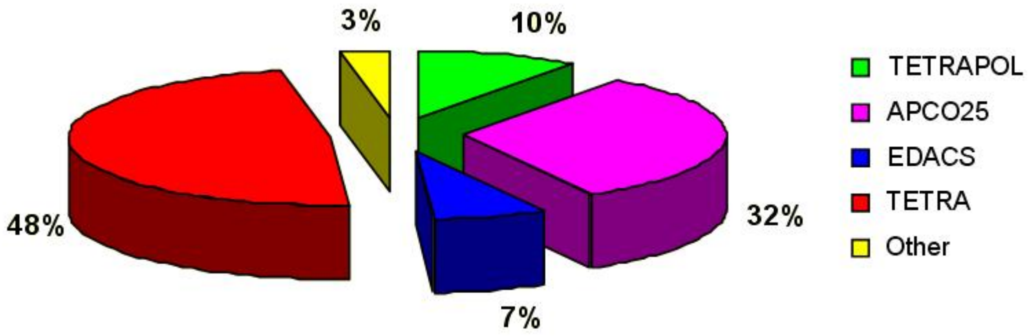

Figure 3-11 Worldwide PMR market comparison [4].

3.4 APCO25

Joint effort of Association of Public Safety Communications Officials International (APCO), the National Association of State Telecommunications Directors (NASTD), selected Federal Agencies and the National Communications System (NCS) produced a set of standards called Project 25 that define digital radio communications system architectures capable of serving the needs of Public Safety and Government organizations [2]. In the literature, different names such as Project 25, P25, APCO, APCO Project 25, APCO25, etc. are used for the standards. To avoid from the misunderstanding "APCO25" will be used in the content of this thesis.

3.4.1 Capabilities of APCO25

In this section the capabilities of APCO25 are studied in the light of the requirements explained in CHAPTER 2.

APCO25 open system standards

- Involves digital land mobile radio services for local, provincial and national public safety organizations.
- Define the interfaces, operation and capabilities of any APCO25 compliant radio system. APCO25 compliant radios can communicate in analog mode with conventional radios and in either digital or analog mode with other APCO25 radios.

- Allows any manufacturer to produce an APCO25 compatible radio product.
- Supports both trunked and conventional radio systems.

The other important capabilities of APCO25 are given in the following sections.

3.4.1.1 Interoperability

Radio equipment that is compatible with APCO25 standards permits responders from different agencies or areas to communicate directly with each other. This allows agencies on the provincial or local level to communicate more effectively with each other when necessary.

3.4.1.2 Compatibility

APCO25 equipment can be used in any configuration that is typically found in existing VHF/FM analog systems. Base Stations, remote bases, repeaters, voting, and simulcast systems are all configurations of APCO25 conventional systems. Transmitter RF power output levels and receiver sensitivity levels of APCO25 equipment are very similar to those of conventional analog equipment. APCO25 equipment can therefore be used in a “one-to-one replacement” of analog equipment.

APCO25 Phase 1 digital radio equipment is compatible with standard analog FM radios. This supports an orderly migration into mixed analog and digital systems, allowing users to gradually upgrade radios and related infrastructure.

APCO25 radios operate in analog mode to older analog only radios, and either analog or digital mode to other APCO25 radios (Figure 3-12). APCO25 Phase 2 radio systems will include a Phase 1 conventional mode for compatibility with Phase 1 APCO25 equipment.

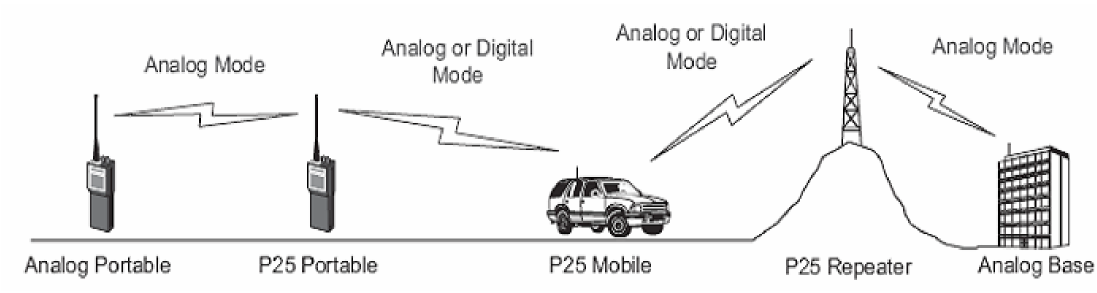

Figure 3-12 Compatibility of APCO25.

3.4.1.3 Security

The encryption used in APCO25 is optional, allowing the user to select either clear (un-encrypted) or secure (encrypted) digital communication methods. The encryption keys also have the option of being re-keyed by digital data over a radio network. This is referred to as Over The Air Re-keying (OTAR). This capability allows the radio systems manager to remotely change encryption keys.

3.4.2 Services Provided by APCO25

Some of the services that APCO25 provides to the users are listed below [8].

- *Routine group call*: This is a transmission that is intended for a group of users in a radio system. Typically, it is the type of call that is made most often. These calls are typically made when the PTT switch is asserted.

- *Emergency group call*: This is a transmission that is intended for a group of users in a radio system during an emergency condition. The definition of an emergency condition depends on a system's operators, but it typically signifies an exceptional condition with more urgency. These calls are typically made after the emergency switch is asserted.

- *Individual call*: This is a transmission, which is addressed to a specific individual radio. The individual radio's address to which the call is directed is called the destination address. These calls are typically made after the destination address is entered into the radio.

- *PTT switch*: A push-to-talk (PTT) switch is activated when an operator wishes to transmit, and released when a transmission is finished.

- *Channel selector*: The channel selector is a switch or control that allows the operator of a radio to select a radio's operational parameters. The operational parameters that can be selected include the following items: Transmit frequency, transmit network access code, talk group, other parameters for setting the vocoder and encipherment functions. For example, the enciphering key variable may be selected.

- *Emergency switch*: The emergency switch is asserted by a radio operator for emergency calling. Once this switch is asserted, the emergency condition remains asserted until it is cleared by a different means, e.g. turning the radio off.

3.4.3 Interfaces of APCO25

This section introduces the APCO25 interfaces that are integral to the APCO25 radio systems. APCO25 defines six interfaces to an RF Sub-System (RFSS), one peripheral interface and one over-the air interface (Figure 3-13).

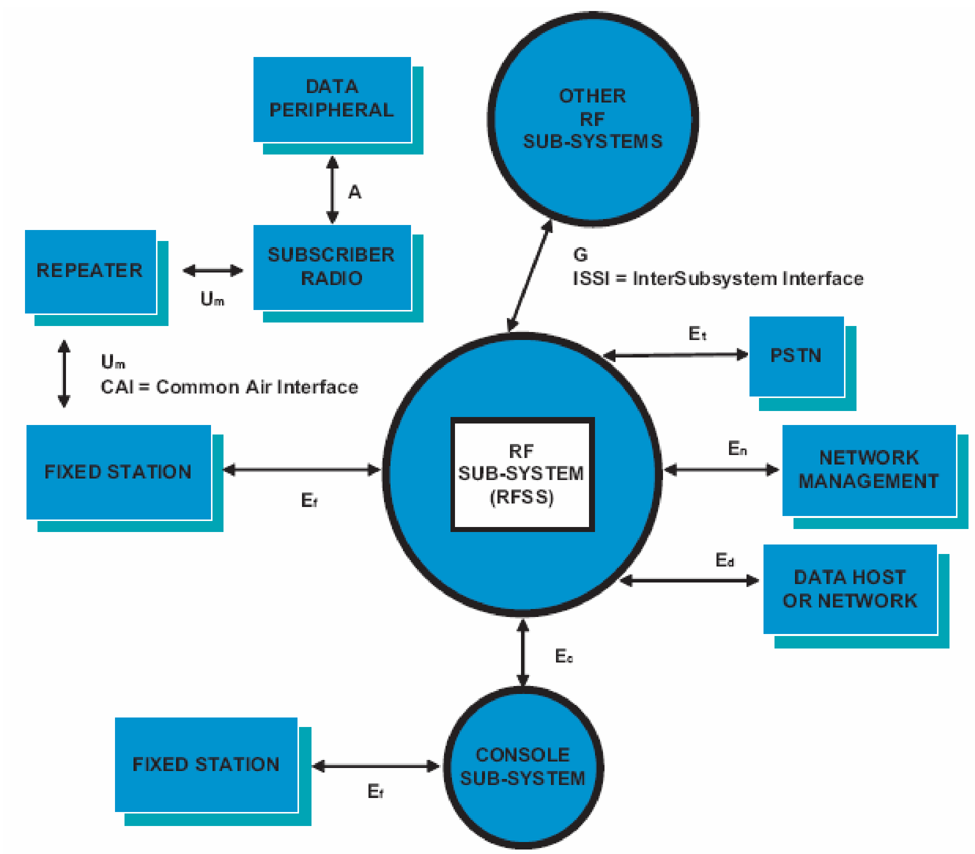

Figure 3-13 APCO25 interfaces.

3.4.3.1 RF Sub-System

RF Sub-System (RFSS) is an infrastructure which is surrounded by the APCO25 interfaces. The RF Sub-System can be a single radio station or multiple stations whose only requirement is that the equipment supporting the Common Air Interface. The RF Sub-Systems are the building blocks for wide-area system construction and will connect with any other configuration of equipment or RF Sub-Systems.

3.4.3.2 Common Air Interface

The Common Air Interface (CAI) is a standard providing the communications between APCO25 radios manufactured by the same or different companies. Communications between APCO25 radios are done at 9.6 kbps and with FDMA channel access. Several processes take place to convert information for transmission.

The Common Air Interface uses an IMBE™ vocoder to convert speech to a digital format for communication. This voice information is then protected with error correction coding to provide protection over the channel. The voice information and error correction are then transmitted with additional encryption information, unit identification, and low speed data to fully utilize the 9.6 kbps of channel capacity in the Common Air Interface.

3.4.3.3 Inter Sub-System Interface

The Inter Sub-System Interface (ISSI) is under development. The Inter Sub-System Interface permits multiple RF Sub-Systems to be interconnected together into wide-area networks. The interface is designed to give system designers the flexibility to combine any number of RF Sub-Systems of any size. The Inter Sub-System Interface also provides a common meeting place for RF Sub-Systems of different technologies (TDMA, FDMA, micro-cell) and different RF bands.

3.4.3.4 Telephone Interconnect Interface

APCO25 requires an open interface to telephone networks. The Telephone Interconnect Interface (Et) supports both analog and ISDN telephone interfaces, providing for selective use of proven standard telephone interfaces currently in use.

The Telephone Interconnect Interface defines a 2-wire loop start and a 2-wire ground start connection between the RF Sub-System and the PSTN or a PABX. The Telephone Interface deals only with voice service because it has been assumed that circuit connected data services would access a telephone network via a modem and connect to a data port on the radio system.

3.4.3.5 Network Management Interface

The Network Management Interface (En) is under development. The Network Management Interface defines a network management interface to all RF Sub-Systems.

3.4.3.6 Data Host or Network Interface

The Data Host or Network Interface (Ed) defines four different types of data connectivity. These include a native open interface for connecting host computers, as well as the requirement to support three different types of existing computer network interfacing (TCP/IP, SNA, and X.25).

3.4.3.7 Data Peripheral Interface

The Data Peripheral Interface (A) defines protocols by which mobile and portable subscriber units will support a port through which laptops, terminals, or subscriber unit peripherals may be connected.

3.4.3.8 Fixed Station Interface

The Fixed Station Interface provides for communication between a Fixed Station (FS) and either an RF Sub-System (RFSS) or a Console Sub-System. The Fixed Station Interface defines a set of mandatory messages, supporting analog voice, digital voice (clear or encrypted), and data (under development). These messages will be of a standard format passed over the interface.

3.4.3.9 Console Sub-System Interface

The Console Sub-System Interface (Ec) is under development. The Console Sub-System Interface (CSSI) defines a multi-channel digital interface. This interface is capable of supporting standard protocols to enable interoperable support functionality. The CSSI defines basic messaging structures to interface a console sub-system to an RFSS. The CSSI can be supported using a variety of networking technologies and topologies, from a simple star configuration to an intelligent backbone network.

The physical interface is an Ethernet 100 Base-T with an RJ45 connector. The CSSI will support Ethernet 10 Base-T and 1000 Base-T as an optional physical interface. The CSSI will optionally support auto-sensing. Other interfaces may be installed as a manufacturer's option.

3.4.4 Frequency Bands

APCO25 frequency bands are VHF (136 – 174 MHz) and UHF (403 – 512 MHz, 806 – 870 MHz). In addition, 700 MHz (746 – 806 MHz) digital public safety band is adopted by APCO25 Phase 1 for digital interoperability.

3.4.5 Channel Usage

APCO25 uses FDMA (Frequency Division Multiple Access) technique. In Phase 1, the bandwidth is narrowed to 12.5 kHz, which is half bandwidth of the analog systems; in Phase 2 (not completed) it is divided by 2 again and narrowed to 6.25 kHz (Figure 3-14).

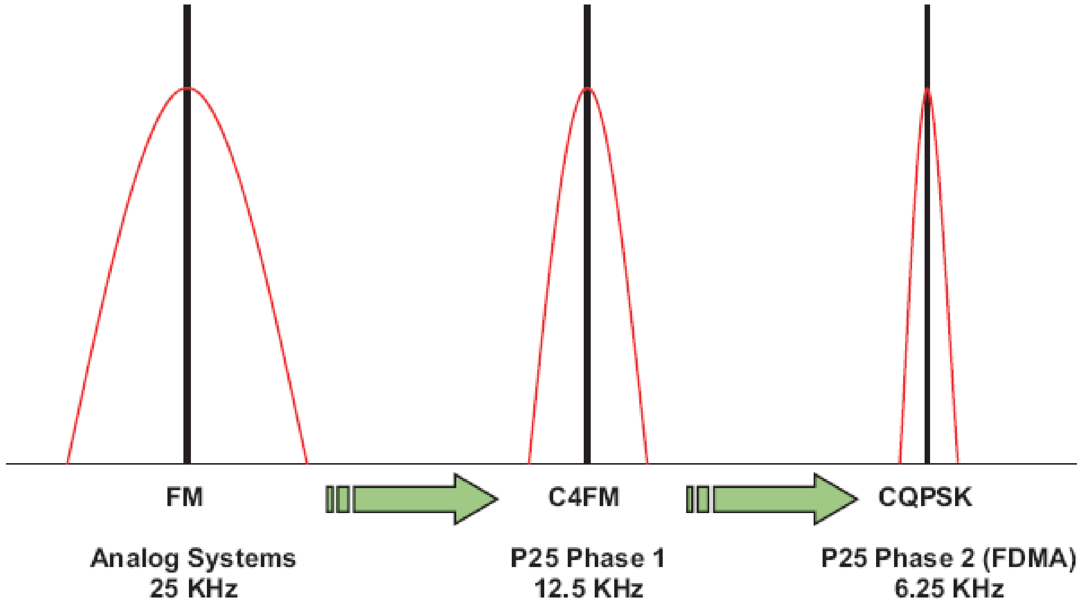

Figure 3-14 Channel usage in APCO25.

3.4.6 Trunking In APCO25

APCO25 trunking standards specify a control channel, and one or more traffic channels. The control channel can be a dedicated control channel, which operates as a control channel only, or optionally, a composite control channel, which operates as a control channel or as a traffic channel when all other traffic channels are busy. A secondary control channel can also be specified, to be used when the primary control channel is unavailable. The traffic channels of a trunked system can be encrypted and the control channel of a trunked system may also be optionally encrypted.

The steps of the trunking system operation are as follows.

1. The subscriber unit scans pre-programmed channels to catch the Outbound Signaling Packets (OSPs) that are continually broadcast from the trunking controller.

2. The subscriber registers with the trunking controller (RFSS). The trunking controller can restrict access to only valid subscriber units and can record where that subscriber is located within the network.

3. The trunking controller allows the subscriber to access the network and assigns a Working Unit ID (WUID) and Working Group ID (WGID) to the subscriber.

4. The subscriber monitors the control channel until the subscriber requests a traffic channel.

5. The subscriber requests a traffic channel for voice or data communications.

6. The trunking controller gives a traffic channel to the requesting subscriber and informs the recipients with the voice or data message.

7. All subscribers in the Talk Group access the traffic channel and communicate voice or data message.

8. Call Termination: All subscribers in the talk group return to Idle and monitor the control channel.

3.5 TETRA

TETRA (Terrestrial Trunked Radio, approved by the European Telecommunications Standards Institute (ETSI)) is a wireless communication standard for Private Mobile Radio (PMR) and Public Access Mobile Radio (PAMR) applications.

The TETRA standard is complex and extremely comprehensive. A fully specified TETRA radio will be more advanced than a GSM handset and able to perform a wider range of functions [13]. TETRA comes in two basic forms: the TETRA voice and data system (TETRA V+D), which is designed for general purpose use and provides voice and data circuit-switched connections, and the TETRA packet data optimized (TETRA PDO) standard, which is designed for packet data applications. Both standards operate over the same physical TETRA network but are designed to be optimized for different purposes. It was developed primarily to meet the needs of the most demanding professional radio users who need fast one-to-one and one-to-many radio communication using voice and data in their daily work. Users are typically public safety and security organizations such as police, fire and rescue forces [3].

3.5.1 General System Overview

Much of the TETRA network architecture is similar to that of GSM. The “Direct Mode Communication” allowing direct, mobile-to-mobile communications, in areas where no network coverage is available and ad-hoc coverage is required (emergency, utility services, etc.) shown in Figure 3-15 is the main difference between TETRA and GSM network architectures. Mobile GSM stations cannot be connected to each other without a base station.The operation of the TETRA system is also similar to the operation of GSM. When a radio is turned on, it searches for a control channel and registers itself to the network. The coverage area is separated into location areas, and a mobile station is only registered to the cells in its current location area. When the location area changes station need to reregister to the new location area.

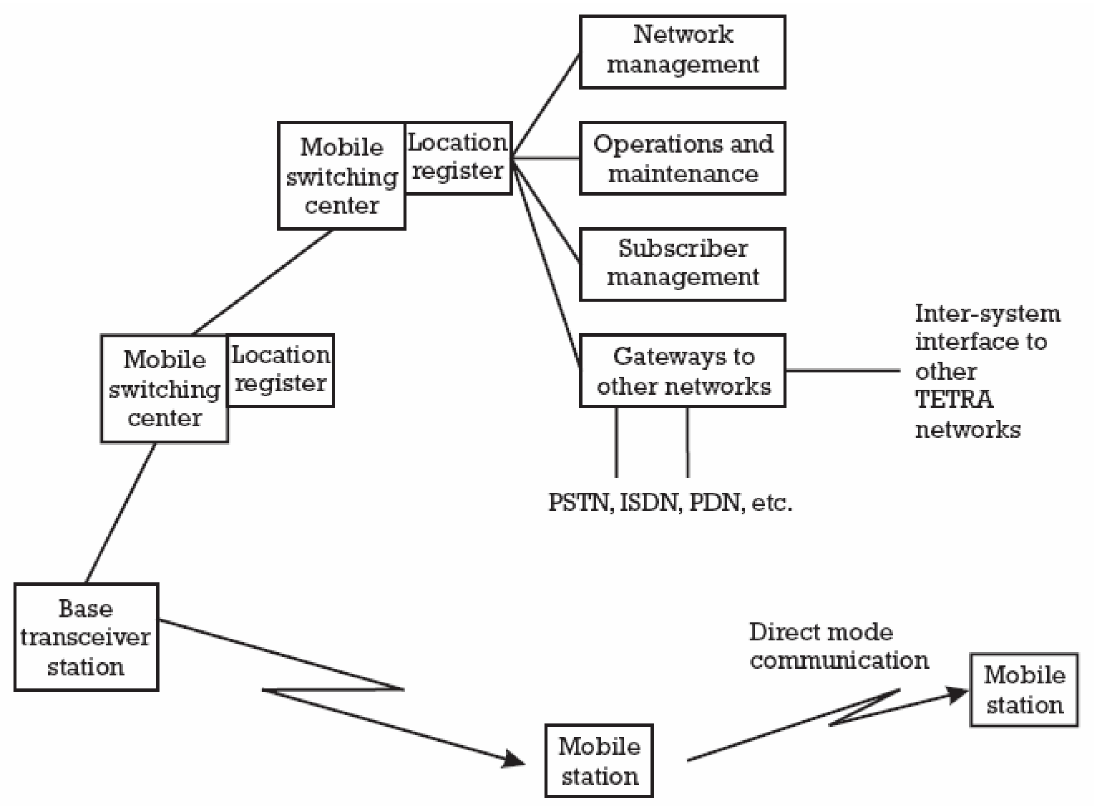

Figure 3-15 TETRA network architecture.

3.5.2 Capabilities of TETRA

In this section the capabilities of TETRA are studied in the light of the requirements explained in CHAPTER 2.

TETRA standards utilizes

- The latest trunking technology whose controller knows
    - The individual and group identity of all radio units registered on the system.
    - The individual identity and time radio units registered on the system.
    - The individual identity and time radio units de-registered from the system.
    - The individual and group identity, time and duration of all messages.
- A four time slot TDMA technology offering
    - Improved data transmission in poor RF signal conditions.
    - On demand bandwidth which can be increased as required for specific applications.
    - Concurrent voice and data transmission.
    - Full duplex voice communications.

The other important capabilities of TETRA are given in the following sections.

3.5.2.1 Interoperability

The interoperability ensures that TETRA equipment from one-manufacturer functions with TETRA equipment from another manufacturer and enables an open muti-vendor market. The interoperability of TETRA is certificated by an independent certification body following the process shown in Figure 3-16.

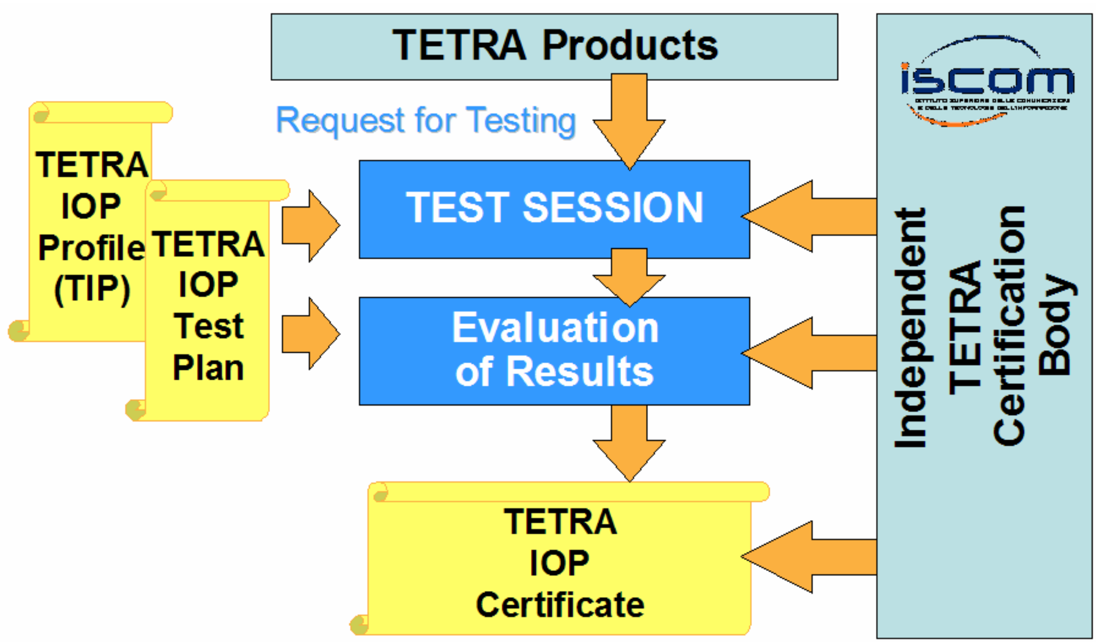

Figure 3-16 TETRA interoperability (IOP) certification process.

3.5.2.2 Compatibility

The TETRA system was a completely new design based entirely on digital modulation and does not provide for conventional FM radio support.

3.5.2.3 Security

TETRA security is provided mainly by two ways: Authentication and encryption.

- *Authentication:* Its aim is to verify that the identity of a user on the radio link (radio or fixed network user) matches the identity declared by the entity itself; the procedure is activated at registration time and can be later repeated periodically.

- *Encryption:* Encryption is implemented in two manners: Air Interface Encryption and End-to-End Encryption

  - *Air Interface Encryption:* This service allows a secure radio link to be set up between the mobile subscribers and the fixed network (the base station). The network for any ongoing call activates this facility; also allows the signaling information to be protected. Encryption is activated only when the user requesting the call registers; the degree of protection is lower than with end-to-end encryption, since it is limited to the air interface. Air interface and end-to-end encryption are independent of each other, so if both are adopted, the information on the radio link will be encrypted twice.

- *End-to-End Encryption:* This service allows secure voice and data calls to be set up between mobile and fixed users in the system (point-to-point, multipoint and broadcasting connections are possible). Since this is an end-to-end service, confidentiality is guaranteed on any link on which the call is routed. In this sense, it allows a higher degree of protection than air interface encryption. For end-to-end encryption, a number of cipher keys are available for each user with different levels of complexity. In mission-critical situations, high-ranking users will be allowed to use high-protection encryption for communications with each other and with the control center, while they will be able to use lower-level encryption during communications with normal users.

3.5.3 Services Provided by TETRA

TETRA services can be divided into the main categories:

- *Teleservices*: A teleservice provides the complete capability for communication between users, including the terminal functions. Teleservices supported by TETRA are clear or encrypted speech in each of the following calls.

  - *Individual Call:* Connects one user of the network with one other user, like public telephone system.

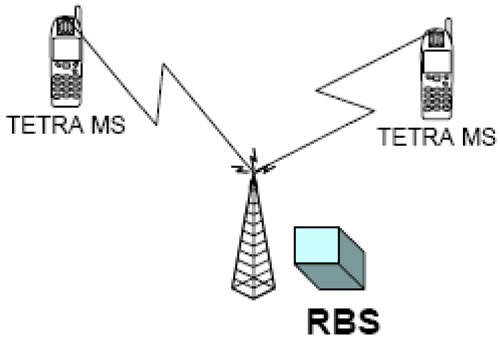

Figure 3-17 Individual call.

- *Group Call:* Connects one user with a group of users. It is possible to configure a group call where it is necessary for every user to confirm the reception of the call. This enables the calling station to be sure that all users have received the call.

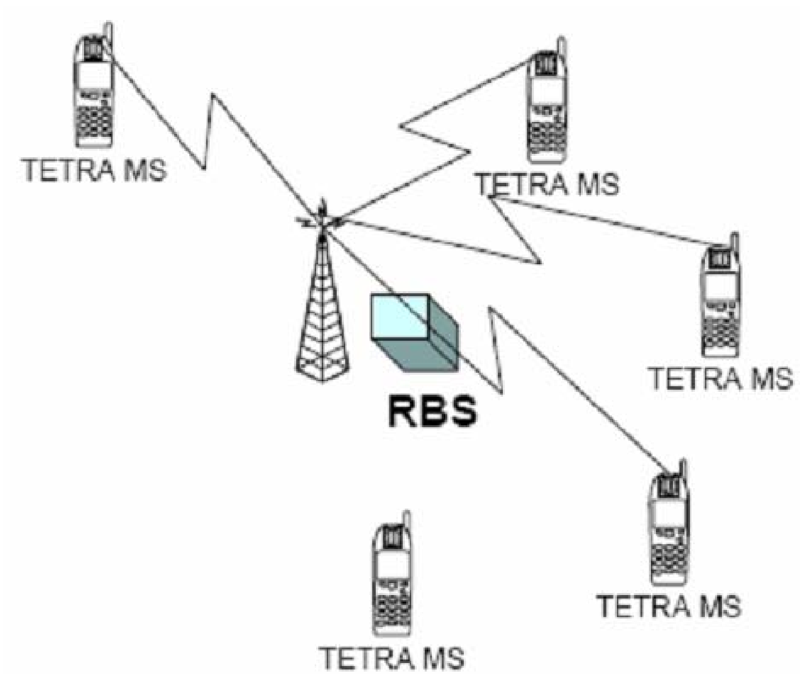

Figure 3-18 Group call.

- *Acknowledged Group Call:* This is the same as the group call described above, except that a call is not established unless acknowledgment is received from a defined number of called parties that are ready to communicate.

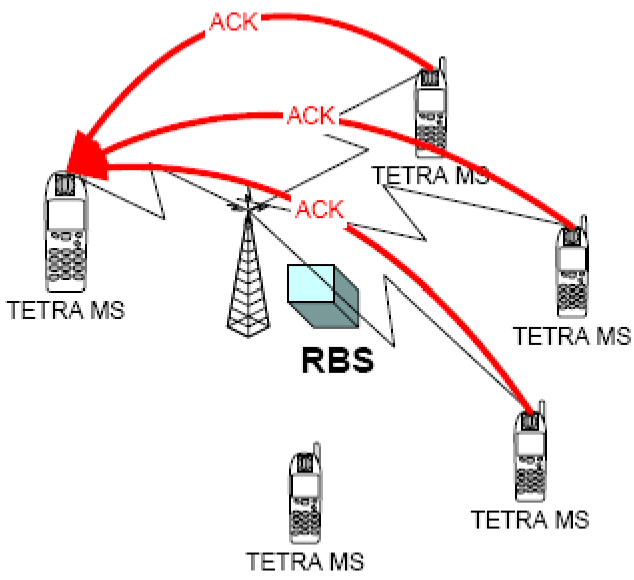

Figure 3-19 Acknowledged group call.

- *Broadcast Call:* A broadcast call is transmitted from a control center to all users for giving information. Unlike group call, the users do not confirm the reception of the call.

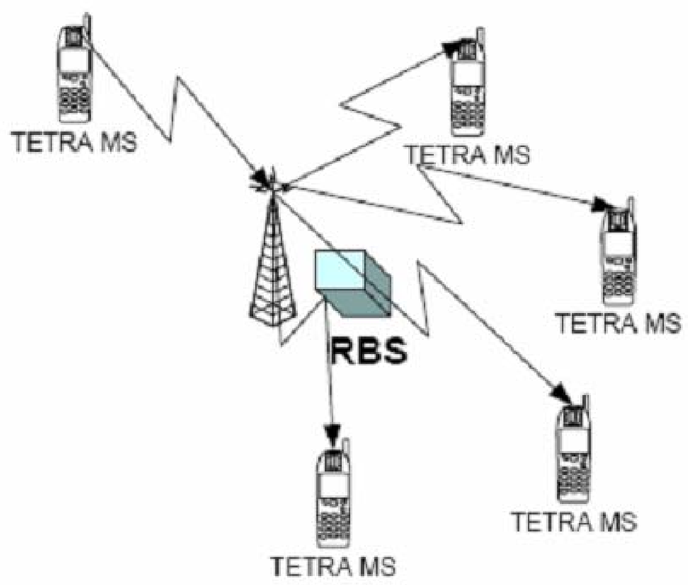

Figure 3-20 Broadcast call.

- *Emergency Calls*: Handled by the TETRA MSC with a high priority to enable a quick connection to a dispatcher or a group.

- *Direct Mode (DMO):* Two users connected to each other directly in simplex mode without using a TETRA network.

- *Open Channel:* A communication service very similar to an analog two-way radio channel, where every participant can talk or listen freely.

- *Call Include:* Allows entrance of additional users to a group call that is already established and running.

▪ *Bearer Services*: A bearer service permits the transmission of user-information signals between user network interfaces. TETRA bearer services are designed for data transfer.

- *User Status Transmission:* Used to transmit short, predefined status messages like “Patrol car on duty”, “Work order received” or “Fire engine back in fire station” from the user towards the dispatching control center or vice versa.

- *Short Data Service:* Transmits short text messages among the users. This service is very similar to the Short Message Service (SMS) in GSM.

- *Circuit Switched Data Services:* Transmits unprotected data (7.2, 14.4, 21.6, 28.8 kbits/sec), low protected data (4.8, 9.6, 14.4, 19.2 kbits/sec) and high-protected data (2.4, 4.8, 7.2, 9.6 kbits/sec).

- *Packet Switched Data Services:* Based on TCP/IP or X.25 protocol, depending on application, with a maximum data rate of 28.8 kbit/s.

▪ *Supplementary Services*: In addition to the tele and bearer services TETRA provides the following supplementary services below [5].

- *Access Priority:* TETRA is expected to be extensively used by the emergency services. Emergency services need and expect to be able to make calls even in times of high network demand. To satisfy this important requirement TETRA radios have access priority. Different users have different priority levels. If a system is busy, the lowest priority call will be dropped to handle the higher priority call. There is also the ability to handle an emergency call.

- *Ambient Listening:* Enables the dispatcher or authorized body to turn on a remote radio unit. In this way, it is possible to monitor possible dangerous situations. If a police officer is in a hostage situation, he may not be able to key up his radio. If the dispatcher can key up the radio without alerting the hostage-taker, the dispatcher can get a good understanding of the situation the officer is in.

- *Discreet Listening:* In the discreet listening mode, the dispatcher, or other authorized body, can listen into any call on their network. The calling parties are unaware that they are being overheard.

3.5.4 Interfaces of TETRA

This section introduces the TETRA interfaces that are integral to the TETRA communications systems.

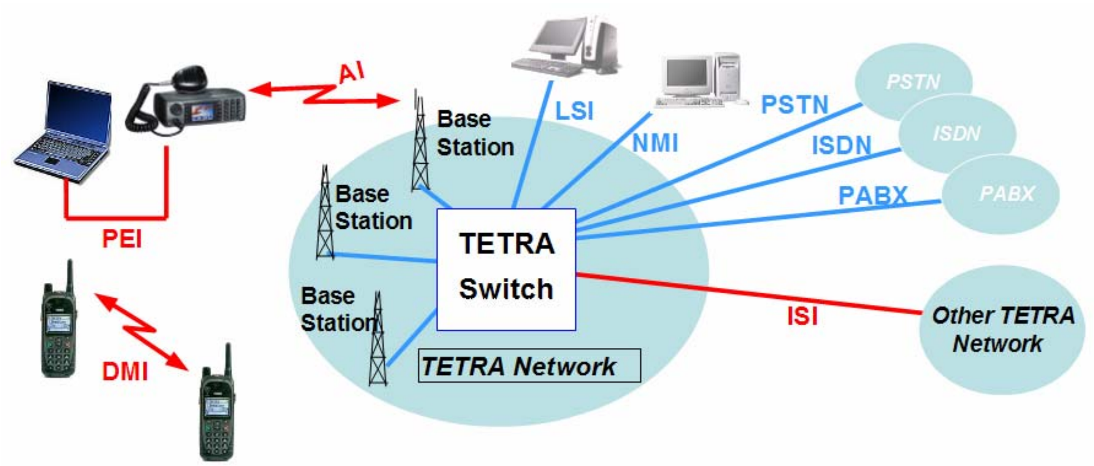

Figure 3-21 Interfaces of TETRA.

3.5.4.1 Air Interface (AI)

The connection of the mobile terminals to the system is provided by this interface. The interface also ensures the interoperability of terminal equipment from different manufacturers.

3.5.4.2 Peripheral Equipment Interface (PEI)

This interface standardizes the connection of the radio terminal to an external device, and supports data transmission between applications resident in the device and the connected TETRA radio terminal.

3.5.4.3 Direct Mode Interface (DMI)

This air interface standardizes the connection of mobile terminals operating in direct mode communication.

3.5.4.4 Line Station Interface (LSI)

The line station interface provides the gateway functions towards external networks. The standard specifies interworking with ISDN networks based on basic rate access (BRA) and primary rate access (PRA) as well as data interfaces (e.g. X.25).

3.5.4.5 PSTN/ISDN/PABX

This standardized interface enables TETRA to interface with the PSTN, the ISDN and/or PABXs as required by both user organizations and application developers.

3.5.4.6 Inter-System Interface (ISI)

This standardized Inter-System Interface (ISI) allows infrastructures supplied by different TETRA manufacturers to inter-operate with each other allowing interoperability between two or more networks without a loss of functionality at the network boundary. There are two methods of interconnection in the standard, one covering information transfer using circuit mode and the other using packet mode. Application developers are expected to utilize this interface when it becomes available on TETRA networks.

3.5.4.7 Network Management Interface (NMI)

As this interface has not been standardized only TETRA manufacturer specific interface specifications are available to support the many network management applications allowing network resources to be created, modified and deleted and information about the status of the network (alarms, performance measurements, traffic load, etc.) to be obtained requiring access to TETRA networks.

3.5.5 Frequency Bands

Since TETRA is a TDMA system, the existence of FDMA channels in the TETRA frequency bands will effect the operation. Noting this, the European regulatory body, CEPT (The Conference of European Postal and Telecommunications Administrations), has recommended a number of frequency bands for use with TETRA based services [9]. In Europe, the frequency bands given in the following table are used by TETRA systems.

Table 3-2 TETRA frequency bands.

Systems \ Bands	Frequency Pair (MHz)	
	Uplink	**Downlink**
Emergency Systems	380 – 383	390 – 393
	383 – 385	393 – 395
Civil Systems	410 – 420	420 – 430
	870 – 876	915 – 921
	450 – 460	460 – 470
	385 – 390	395 – 400

3.5.6 Channel Usage

TETRA uses TDMA (Time Division Multiple Access) technique. The channel bandwidth is 25 kHz and 4 time slots exist in each channel. Generally one of these time slots is used as the control channel and the others are the traffic channels (Figure 3-22).

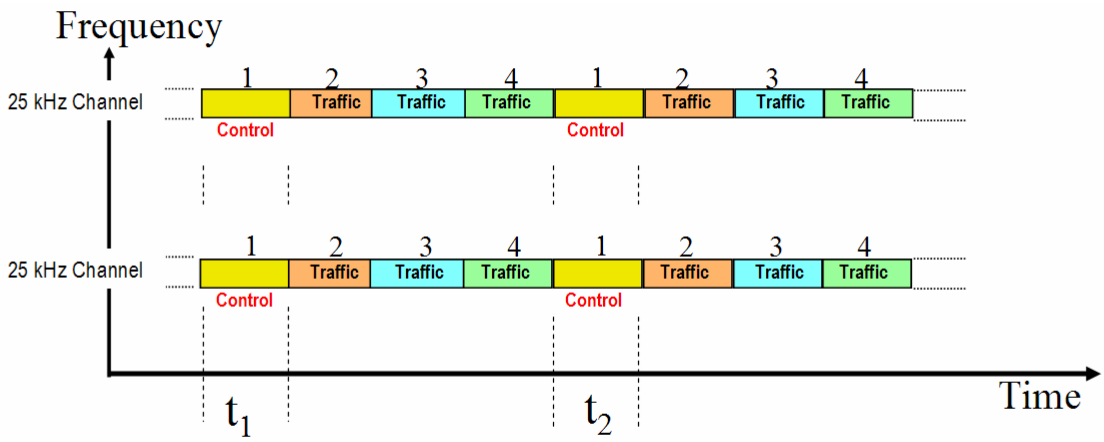

Figure 3-22 Channel usage in TETRA.

3.5.7 Trunking In TETRA

In TETRA, the shared limited resources are the frequencies and timeslots of the radio channels. The trunking of the radio channels is handled automatically by the TETRA network in response to requests signaled by the mobile 0.

For duplex calls, trunking simply consists of allocation of a duplex channel at the start of a call and de-allocation at the end of a call.

For simplex calls, trunking is a more dynamic and complex process, and there are two options, *message trunking* and *transmission trunking*, as well as a hybrid form, *quasi transmission trunking*. The TETRA network determines the type of trunking, and the mobiles obey orders from the base station.

Message trunking is somewhat similar to a duplex call in that both a transmit channel and a receive channel are allocated to the call for the entire duration from the beginning to the end of the call. However, message trunking applies to simplex calls; only one uplink channel and one downlink channel are allocated, regardless of the number of participants in the call.

Mobiles in idle mode listen to the control channel. When a call is set up, mobiles participating in the call are assigned to a traffic channel, which may be on a different frequency. During the call, all of the call participants remain assigned to the traffic channel, and only return to the control channel when the call is cleared down.

Message trunking therefore serves to allocate transmit permission to one mobile at a time, and is more efficient than a duplex call since the uplink and downlink are shared rather than each mobile having an exclusive allocation.

When no user wishes to talk, the traffic channel is quiescent and is effectively wasting radio resources, as it is not carrying traffic. However the channel is immediately available when required.

A more efficient variant of message trunking is *quasi transmission trunking*. In this case a hang timer is used to keep the traffic channel available for a limited period. If no user requests transmit permission within this period, the traffic channel is de-allocated.

Transmission trunking is the most efficient use of the radio resources. A traffic channel is allocated each time a call participant requests transmit permission, and is de-allocated each time the user releases the PTT (Push-to-Talk). The traffic channel is thus available to be allocated to other calls immediately.

Mobiles participating in the call are thus being switched between the control channel and the traffic channel on every PTT press and release. The traffic channel allocated may not necessarily be the same each time, as it may have been allocated to another call in the meantime. Indeed, there may be no free channel available when a call participant wishes to speak, and the mobile will be told to wait until a channel is free. This is known as queuing, and the mobile will typically make a rapid beeping sound to warn the user to wait before speaking.

3.6 APCO25 vs. TETRA

In Table 3-3 some important specifications of APCO25 and TETRA are compared.

Table 3-3 APCO25 vs. TETRA.

PARAMETER	APCO25	TETRA
Frequency bands (MHz)	• 136 – 174 • 403 – 512 • 806 – 870 • 746 – 806	• 380 – 390 / 390 – 400 • 410 – 420 / 420 – 430 • 450 – 460 / 460 – 470 • 870 – 888 / 915 – 933
Duplex separation	3 and 5 MHz (400 MHz band) 39 and 45 MHz (800 MHz band)	5 – 10 MHz (400 MHz band) 10 – 45 MHz (800/900 MHz band)
Backward compatibility	Yes	No
Communication technique	Half Duplex	Half Duplex and Duplex
RF carrier spacing (kHz)	12.5 for C4FM	25
RF output power (W) Standard / COTS products • Base station • Mobile • Handheld	 Standard: COTS: 500 100 100 40 5 5	 Standard: COTS: 0.6 – 40 25 – 30 0.03 – 10 10 0.03 – 3 1 – 3
Receiver sensitivity (dBm) • Base station • Mobile radio	 Static: -116 Dynamic: -108 Static: -116 Dynamic: -105	 Static: -115 Dynamic: -106 Static: -112 Dynamic: -103
Access method	FDMA	TDMA
Traffic channels per RF carrier	1	4
Maximum data transmission rate (kbps)	9.6	28.8
Modulation	C4FM and CQPSK	π/4 DQPSK
Speech codec's • Bit rate (kbps) • Error protection (kbps) • Algorithm	 4.4 2.8 IMBE	 4.567 2.633 ACELP

Table 3-3 APCO25 vs. TETRA (continued).

PARAMETER	APCO25	TETRA
Circuit mode data rate (kbps) • Protected • Non – protected	6.1 9.6	Up to 19.2 Up to 28.8
Packet mode data	IP – Internet protocol	Connection oriented and connectionless
Messaging X.400	No	Yes
Channel coding	• BCH code for network ID • Trellis codes for data • Golay & Hamming codes for voice • Reed – Solomon codes for embedded signals	Convolutional codes with interleaving plus error detection
Encipherment • Multi – algorithm • Multi – key • OTAR	Yes Yes Yes	Yes Yes Yes
Handover	Yes	Yes
Design capability for multiple operators (systems) in same area	Yes	Yes
Direct mode	Mobile-to-mobile Channel scan Repeater Trunking node gateway	Mobile-to-mobile Dual watch Repeater Trunking node gateway
Handset cost (USD)	4000 – 5000	600 – 1000
Call setup time (s)	< 0.5	< 0.3

CHAPTER 4

COVERAGE ANALYSIS ON ANKARA PROVINCE

This chapter is devoted to the comparisons of APCO25 and TETRA outdoor coverage areas. The results obtained from the analyses, which are implemented in Ankara province will constitute us a strong basis to select the suitable system for Turkish geographical structure.

The computer program called NSMS (National Spectrum Management System), which was developed by TÜBİTAK, is used for the coverage analyses. Some capabilities of this program are listed below.

- Program allows user to determine the coverage areas of any system operating in the VHF/UHF and other frequency bands by implementing various propagation models such as Free Space, ITU-R P.1546, ITU-R P.370, Okumura Hata, etc.; and various diffraction models such as Epstein – Peterson, Deygout, Giovaneli, etc. From the available propagation models, ITU-R P.1546-1: Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3000 MHz [9] is selected since APCO25 and TETRA are the terrestrial services operating in the frequency range covered by this recommendation. From the available diffraction models, Epstein – Peterson [17], [18] is selected due to the rough structure of Turkish geography. In addition, Epstein – Peterson model also covers the frequencies of APCO25 and TETRA.

- Program uses Digital Terrain Elevation Data (DTED) in the calculations. The elevation data in our applications do not contain the heights of the man-made buildings and structures. Therefore, they are not taken into consideration.

However, according to ITU-R P.1546-1, representative of the height of the ground cover surrounding the receiver antenna, subject to a minimum reference height value of 10 m. Examples of reference heights are 20 m for an urban area, 30 m for a dense urban area, and 10 m for a suburban area [9]. Urban is selected in our analyses; that is, the receiving antenna is assumed to be surrounded by a ground cover of 20 m.

- Program displays the coverage analysis results on a digital map with color coded signal levels. In addition to the signal levels, the contour, representing the receiver sensitivity can also be displayed on the map. By this way, user can evaluate the coverage area of a system in a visual manner.

- The input parameters of the program are entered using the interface shown in the figures below. (**Note – 1:** The parameters in the figures belong to the APCO25 station at Çaldağ. **Note – 2:** Only the tabs including critical user-defined parameters are shown.)

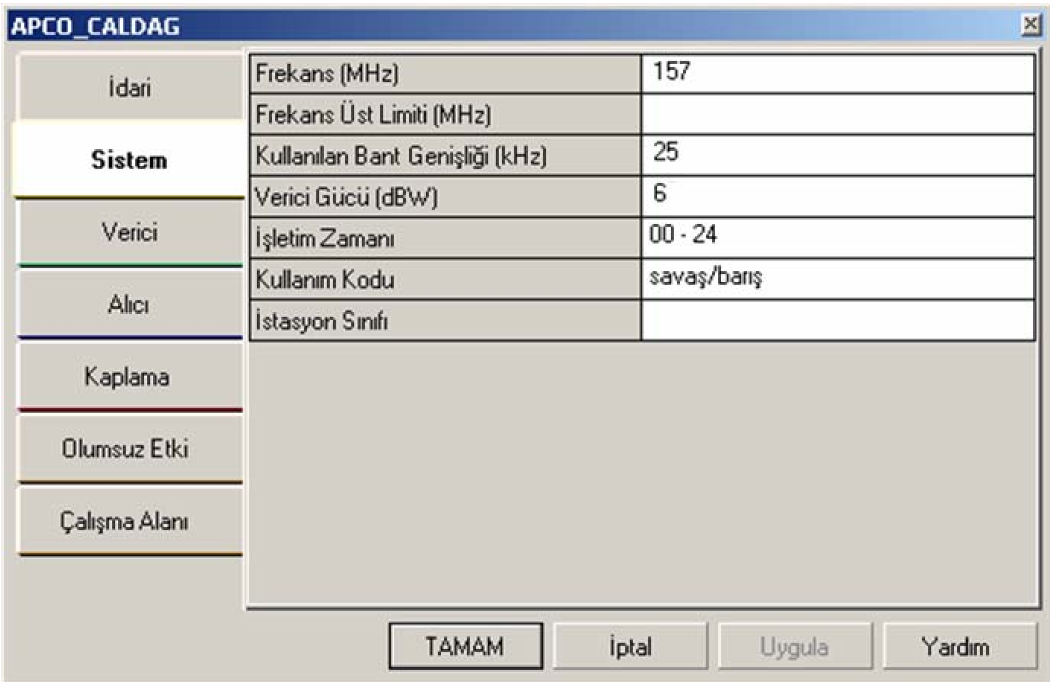

Figure 4-1 NSMS GUI – System parameters tab.

Figure 4-2 NSMS GUI – Transmitter parameters tab.

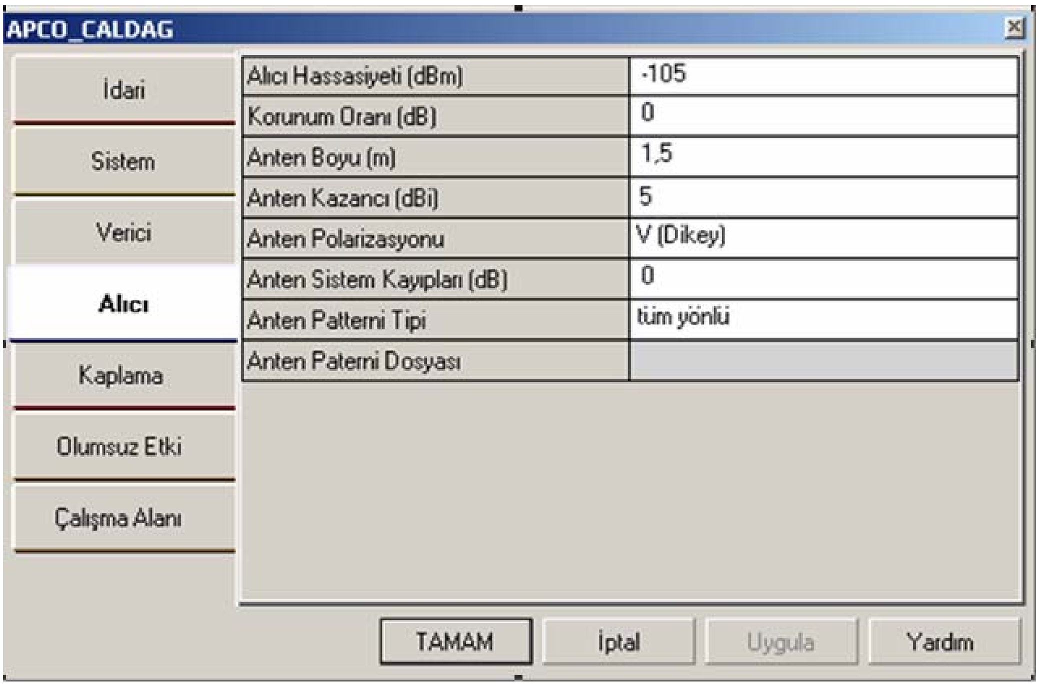

Figure 4-3 NSMS GUI – Receiver parameters tab.

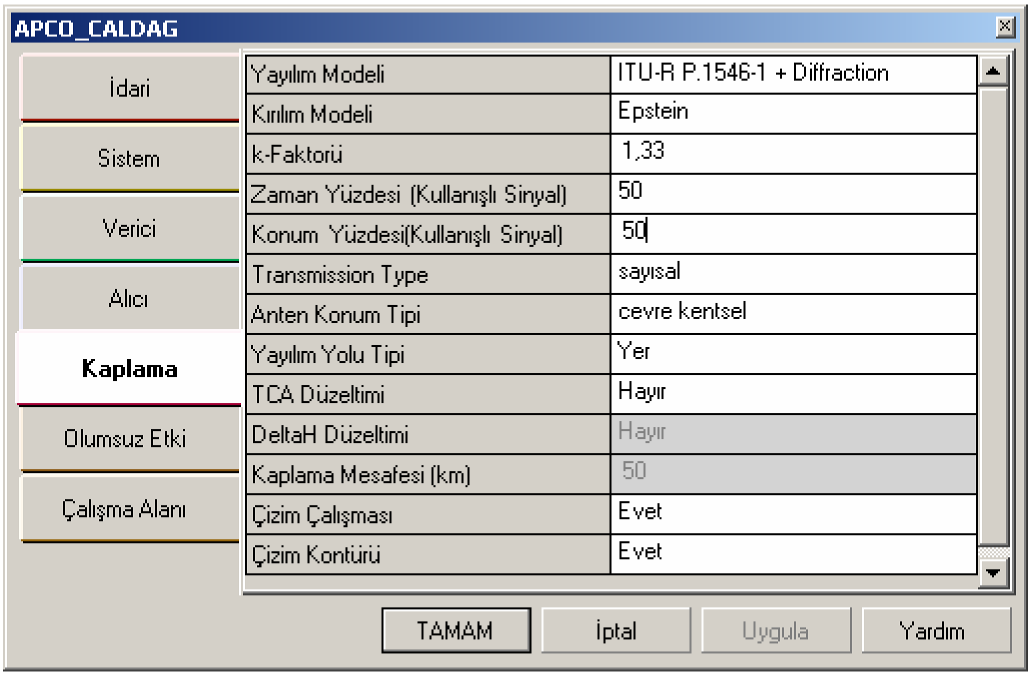

Figure 4-4 NSMS GUI – Coverage parameters tab.

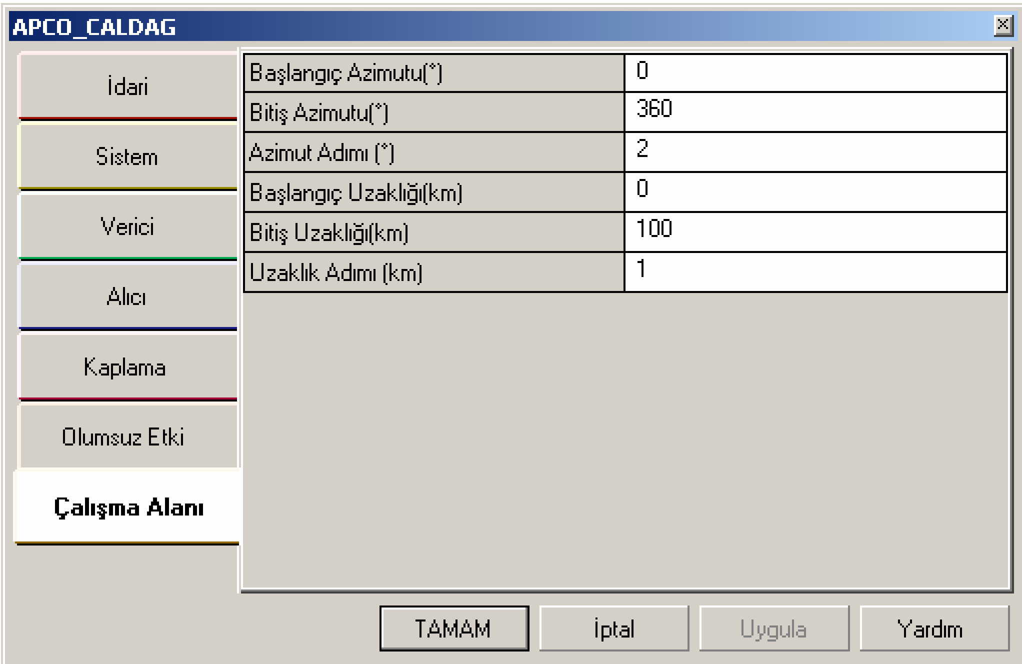

Figure 4-5 NSMS GUI – Study Area parameters tab.

In the analyses, while determining the coverage areas of the systems, uplink (from hand-held radio to base station) and downlink (from base station to hand-held radio) budgets should be calculated and compared. According to the comparison, the parameters of the link having smaller budget will be used in the analyses considering the worst case. APCO25 link budget calculations are as follows.

APCO25 Base Station Parameters:

TX Output Power : 20 dBW
Antenna Gain : 5 dBi
RX Sensitivity : -105 dBm = -135 dBW

APCO25 Hand-held Radio Parameters:

TX Output Power : 6 dBW
Antenna Gain : 3 dBi
RX Sensitivity : -100 dBm = -130 dBW

Downlink Budget (TX: Base Station, RX: Hand-held Radio)

TX Output Power : 20 dBW
TX Antenna Gain : 5 dBi

RX Antenna Gain : 3 dBi
RX Sensitivity : -130 dBW

⇒ Downlink Budget = 20 + 5 + 3 - (-130) = 158 dB

Uplink Budget (TX: Hand-held Radio, RX: Base Station)

TX Output Power : 6 dBW
TX Antenna Gain : 3 dBi

RX Antenna Gain : 5 dBi
RX Sensitivity : -135 dBW

⇒ Uplink Budget = 6 + 3 + 5 - (-135) = 149 dB

APCO25 link budget calculations show that the budget of the uplink is smaller than that of downlink. Similar results have been obtained for TETRA as well. Therefore, in the coverage analyses uplink parameters will be used. Some critical parameters are tabulated in Table 4-1:

Table 4-1 Some critical parameters used in the coverage analyses.

PARAMETER	APCO25	TETRA
Frequency	136 – 174 403 – 512 746 – 806	410 – 420 870 – 888
TX Output Power	6 dBw	4.8 dBw
Receiver Sensitivity	-105 dBm	-103 dBm
TX Antenna Gain	3.0 dBi	3.0 dBi
RX Antenna Gain	5.0 dBi	5.0 dBi
TX Antenna Height	40 m	40 m
RX Antenna Height	1.5 m	1.5 m
TX/RX Antenna Polrz.	Vertical	Vertical
Propagation Model	ITU-R P.1546-1	ITU-R P.1546-1
Diffraction Model	Epstein	Epstein

First group of coverage analyses have been implemented for Ankara city center. When the geographical structure of Ankara is investigated, it is noticed that three high altitude points are advantageous especially for the coverage of center of the city. These points are Elmadağ (1855 m), Çaldağ (1308 m) and Hüseyingazi Mountain (1347 m). Since the base stations to be placed at those points are thought as sufficient to cover the communication needs of different organizations, first group of coverage analyses are implemented for those three points.

Second group of analyses have been implemented for the whole province including all towns and villages. The purpose of this study is to compare the number of APCO25 and TETRA base stations required for covering entire province.

The first group of coverage analyses can be divided into three parts:

- The first part has been implemented to compare the coverage areas of APCO25 and TETRA systems operating in different frequency bands: 157

MHz for APCO25, 415 MHz for TETRA. (Note: 157 and 415 MHz are the frequencies of the APCO25 and TETRA COTS (Commercial Off The Shelf) products.) In addition, to determine the mean coverage distance of both systems, one more analysis has been implemented for APCO25 (at Çaldağ and 157 MHz) and TETRA (at Çaldağ and 415 MHz) by using the distance measurement tool provided by NSMS.

- The second part has been implemented to compare the coverage areas of APCCO25 and TETRA systems operating in 400 MHz frequency band: 415 MHz for both.

- The third part has been implemented to compare the coverage areas of APCCO25 and TETRA systems operating in 800 MHz frequency band: 780 MHz for APCO25, 880 MHz for TETRA.

The results of the first part are shown in Figure 4-6 to 14. These analyses have been implemented for different operating frequencies: 157 MHz for APCO25 and 415 MHz for TETRA.

In Figure 4-6 and Figure 4-8 the coverage map signal levels of the APCO25 and TETRA base stations placed on Çaldağ are shown. The color codes in these figures represent different signal level intervals. In addition to the signal levels, the contours representing the receiver sensitivities are also shown in the figures by thin solid lines. For example (-79 dBm, -66 dBm] interval is respresented by pink in Figure 4-6. This means that the signal levels of pink regions on the map are between -79 dBm and -66 dBm; and, black thin solid line shows the -105 dBm contour which is the sensitivity of APCO25 receiver. The coverage map signal levels for the APCO25 and TETRA base stations placed on Elmadağ and Hüseyingazi Mountain are shown in Figure 4-11, Figure 4-12 and Figure 4-14, Figure 4-15 respectively.

In Figure 4-10, the coverage areas of the APCO25 and TETRA base stations placed on Çaldağ are compared. The coverage contours given in the figure are drawn for -105 dBm and -103 dBm, which are the receiver sensitivities of APCO25 and TETRA's COTS products respectively. The signal levels exceeding the receiver sensitivity are assumed to be understandable. The coverage area comparisons of the

APCO25 and TETRA base stations placed on Elmadağ and Hüseyingazi Mountain are shown in Figure 4-13 and Figure 4-16 respectively.

According to the results shown in Figure 4-6 to 16, APCO25 has larger coverage areas (APCO25 coverage distance is between 25 – 35 km, TETRA coverage distance is between 15 – 25 km). This is due to the lower frequency of APCO25 COTS products. Because the frequencies are different, it is difficult to say that one of the systems is technologically much superior than the other. But, the existence of COTS products of APCO25 at the VHF band is an advantage. On the other hand, there is no information showing that TETRA is not applicable at this band. It should also be considered that the VHF band used by APCO25 is open for civil usage and outside the frequency band (380 – 400 MHz) as recommended by European Union for public safety communications.

The results of the second part are shown in Figure 4-17 to 19. These analyses have been implemented using the same frequency: 415 MHz and the same receiver sensitivities: -105 dBm for APCO25 and -103 dBm for TETRA. The figures show that the coverage areas are almost the same for both of them. Therefore, the selection of APCO25 or TETRA at this band, with the consideration of accordance with European Union standards, will not depend on the extent of the coverage areas.

The outcomes of the third part are shown in Figure 4-20 to 22. These analyses have been implemented using higher frequencies than before: 780 MHz for APCO25 and 880 MHz for TETRA and the same receiver sensitivities again. The results taken from the analyses support the previous ones. The lower frequency usage of APCO25 provides considerable coverage advantage to APCO25 over TETRA.

The results of the second group of analyses, which are implemented to compare the number of APCO25 (at 157 MHz) and TETRA (at 415 MHz) stations for covering entire province, shown in Figure 4-23 to 25. As seen in Figure 4-23 six APCO25 stations at 157 MHz are sufficient to cover Ankara. On the other hand, there are large gaps on the coverage map (shown in Figure 4-24) when the same number of TETRA stations at 415 MHz is used. According to the Figure 4-25, to fill the gaps eleven more TETRA stations are needed.

As a result, the second group of analyses show that seventeen TETRA stations operating at 415 MHz can cover the area covered by six APCO25 base stations operating at 157 MHz.

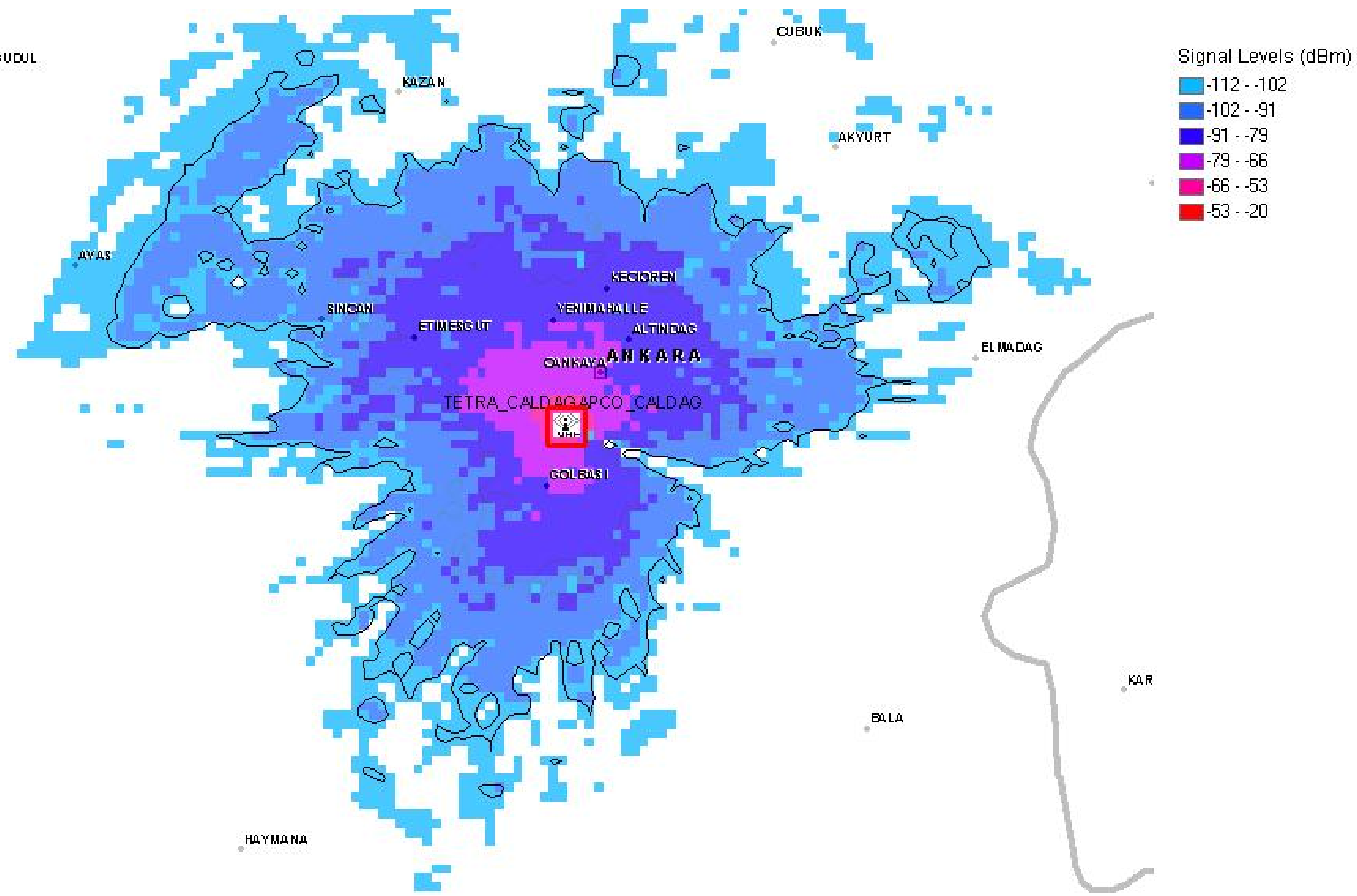

Figure 4-6 APCO25 signal levels (Çaldağ, 157 MHz, Contour: -105 dBm).

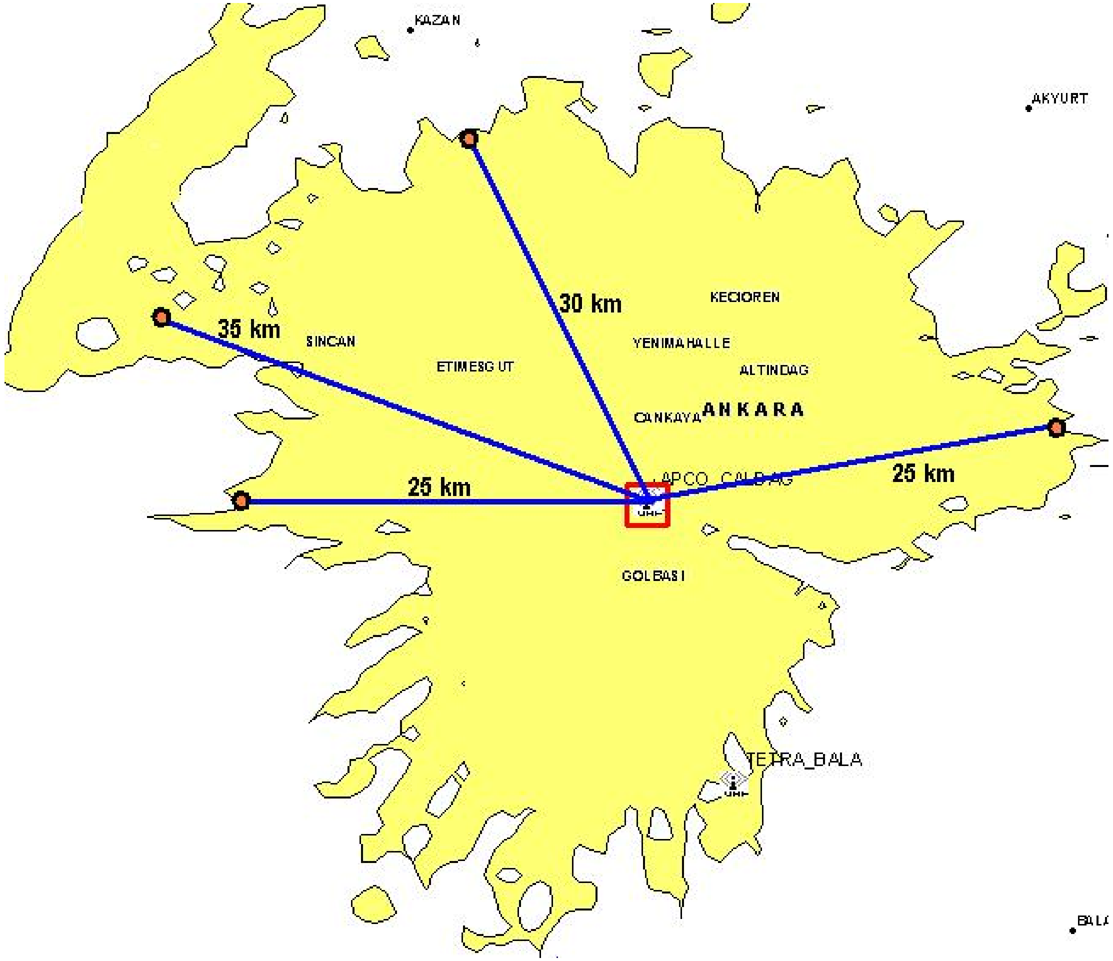

Figure 4-7 Coverage distance measurements of APCO25 station at Çaldağ, 157 MHz.

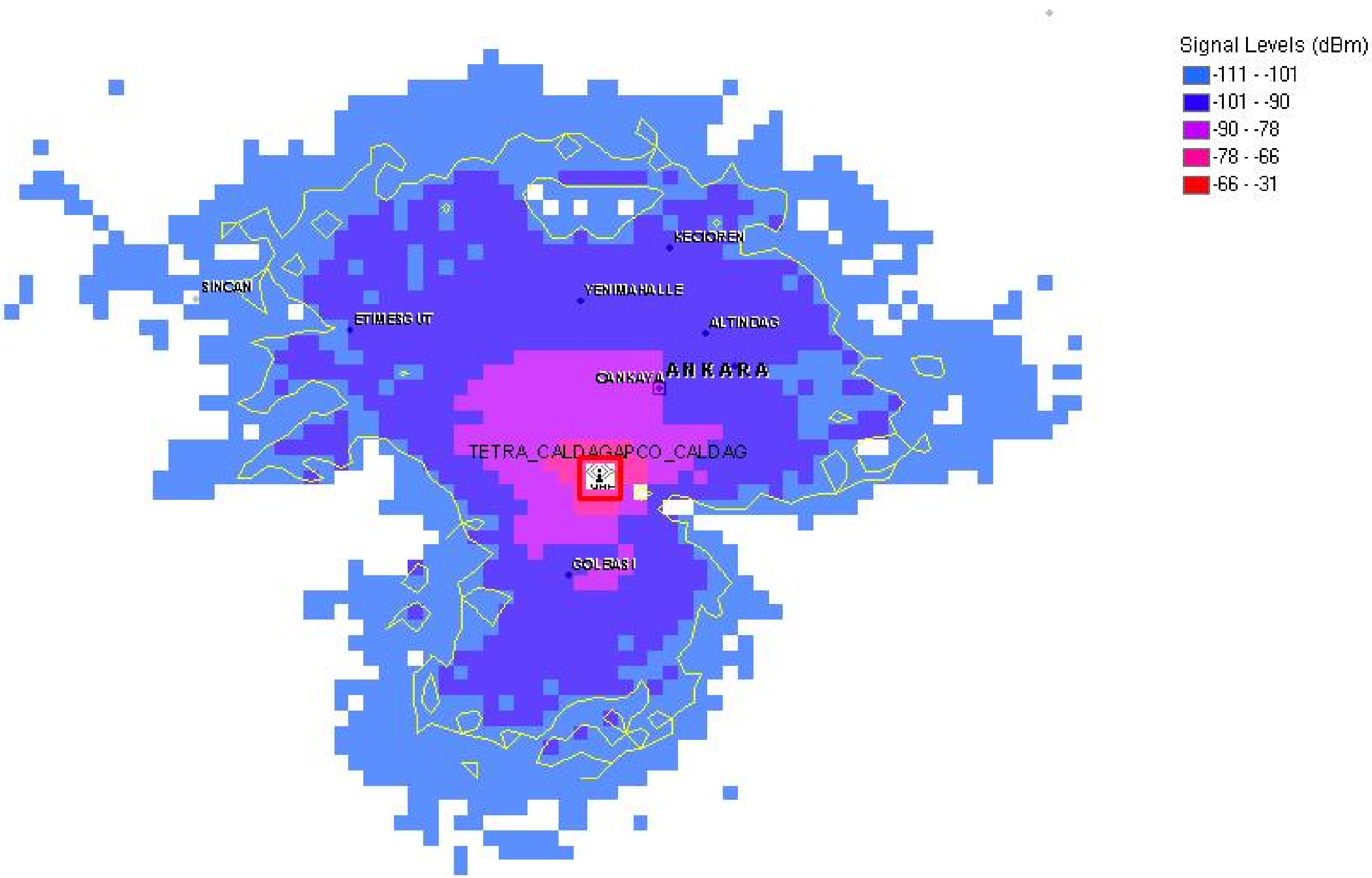

Figure 4-8 TETRA signal levels (Çaldağ, 415 MHz, Contour: -103 dBm).

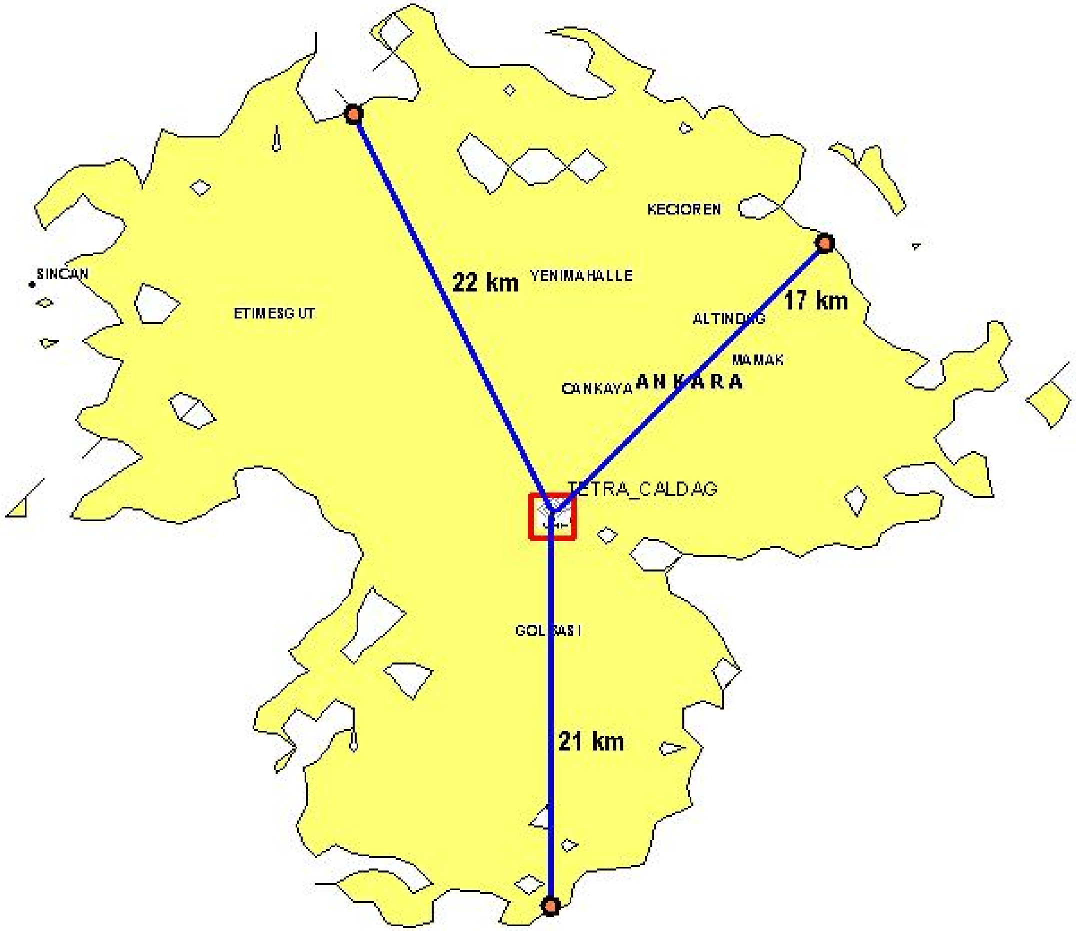

Figure 4-9 Coverage distance measurements of TETRA station at Çaldağ, 415 MHz.

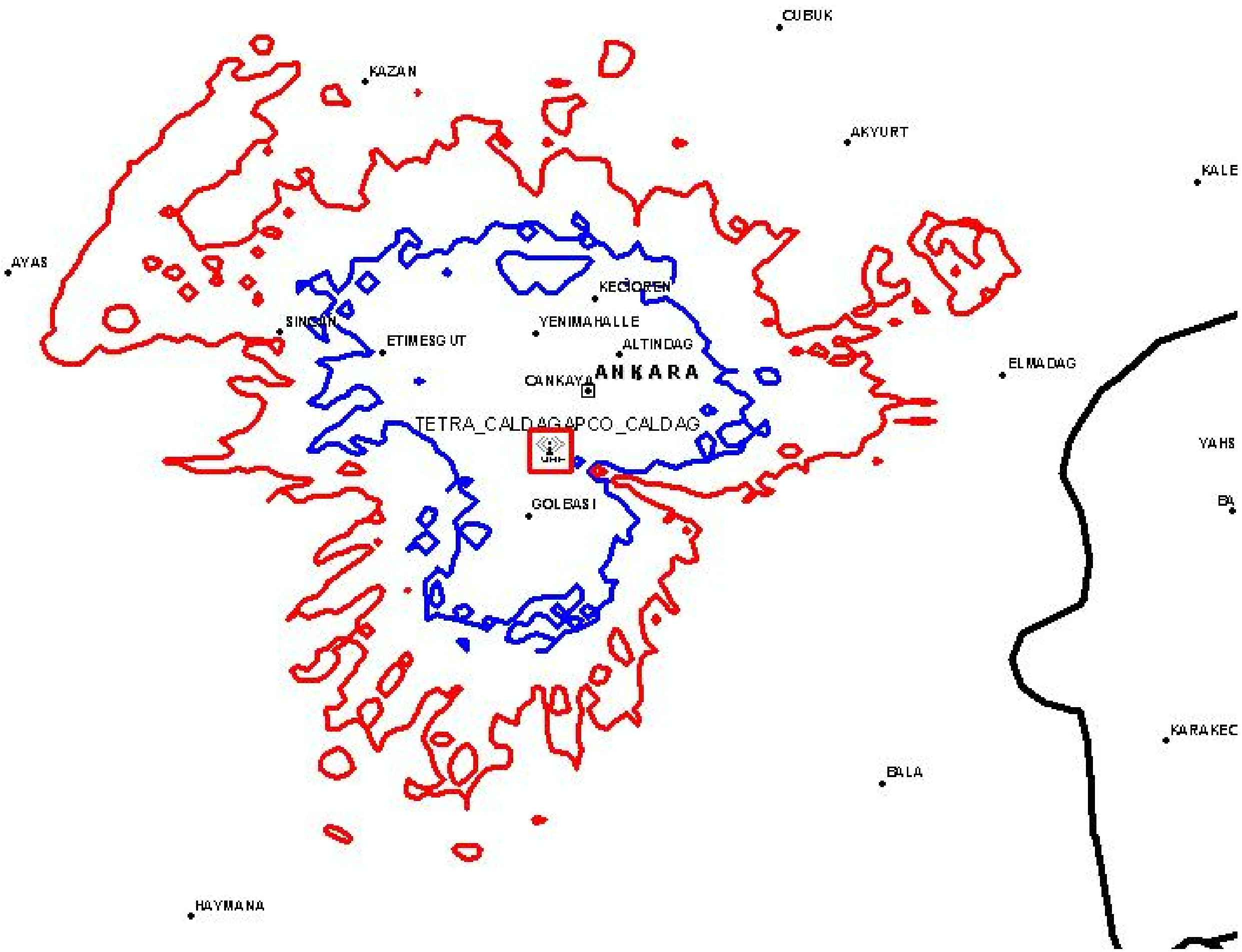

Figure 4-10 APCO25 (157 MHz, -105 dBm red) – TETRA (415 MHz, -103 dBm blue) coverage comparison (Çaldağ).

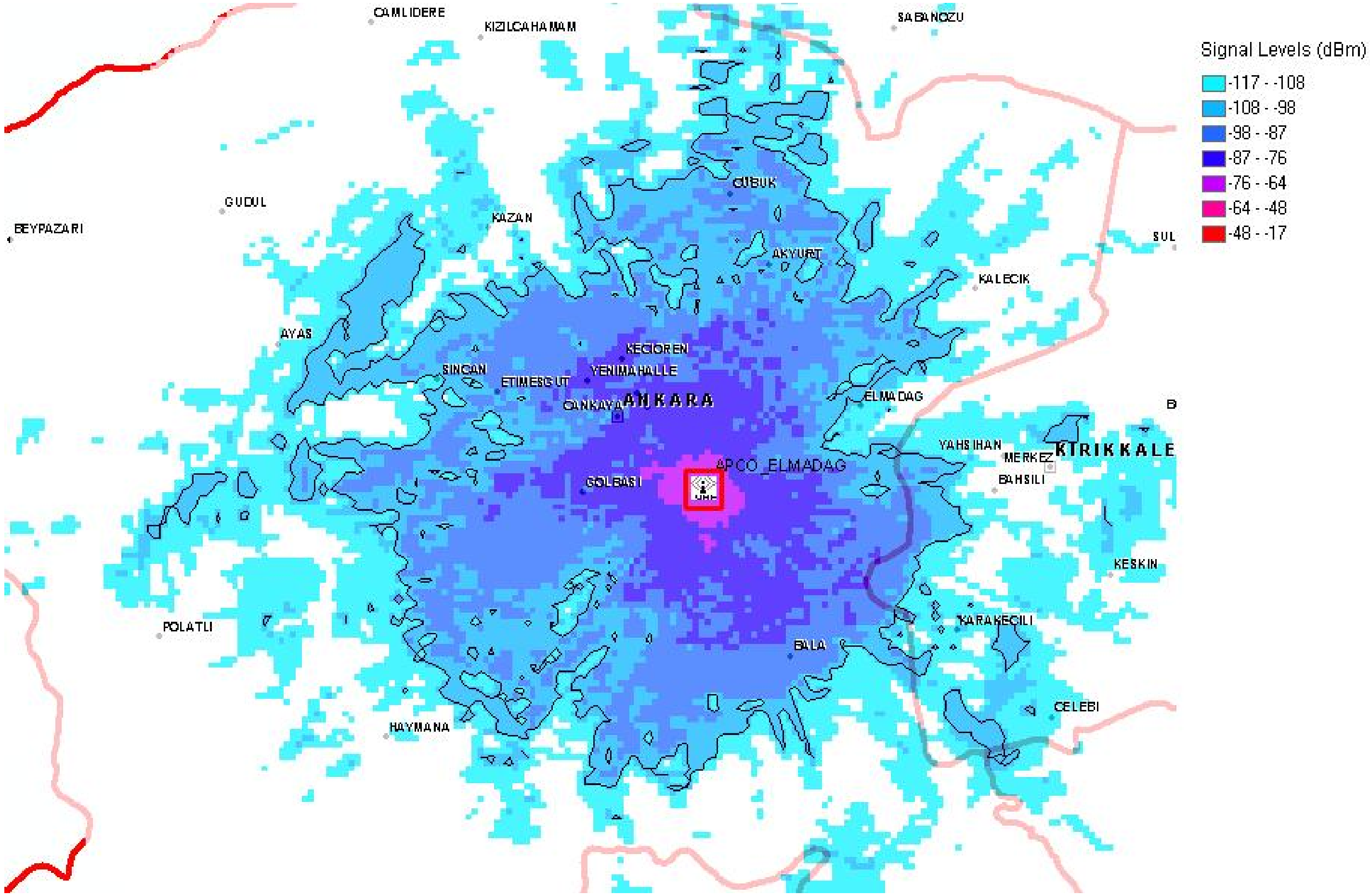

Figure 4-11 APCO25 signal levels (Elmadağ, 157 MHz).

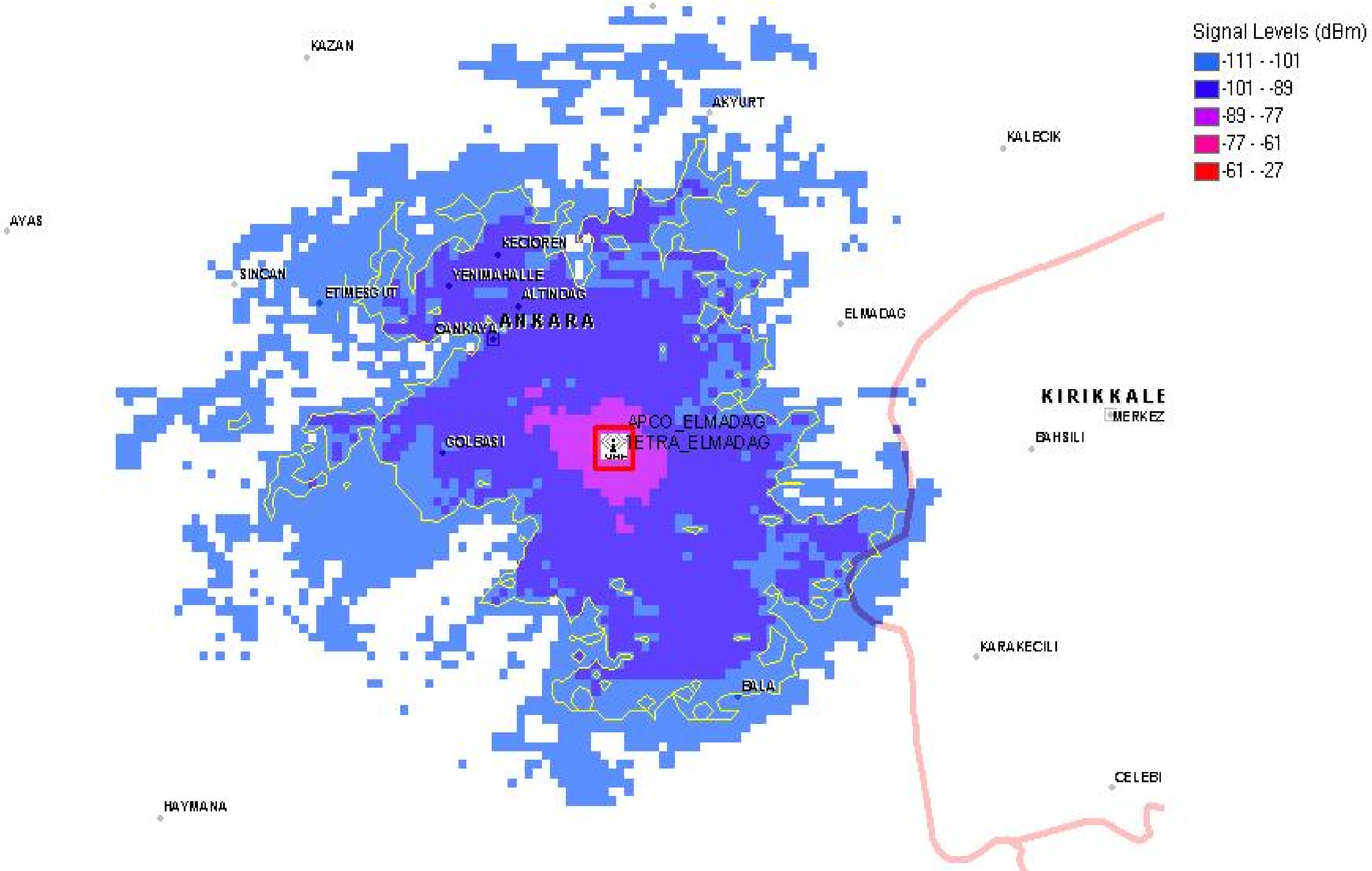

Figure 4-12 TETRA signal levels (Elmadağ, 415 MHz).

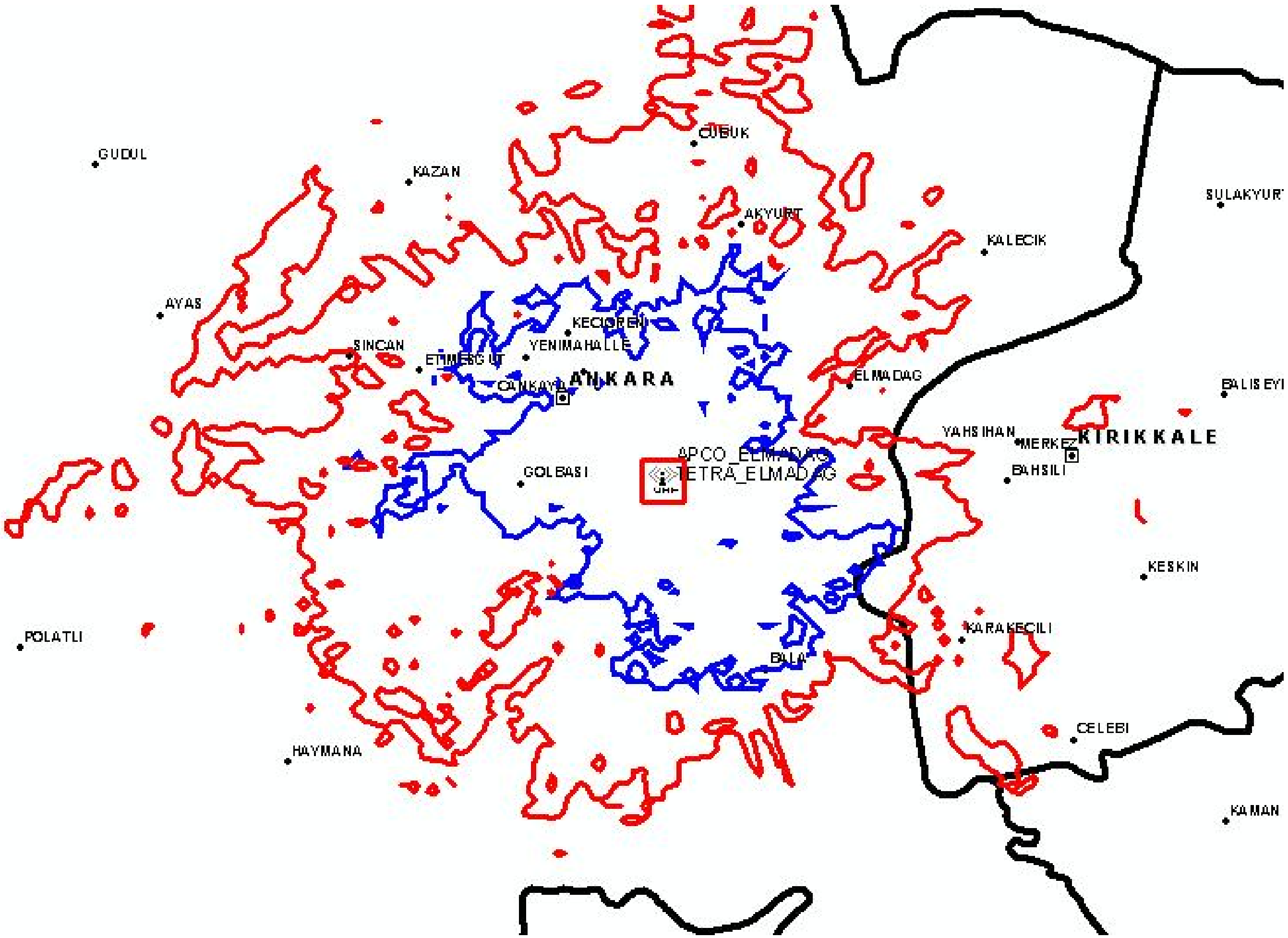

Figure 4-13 APCO25 (157 MHz, -105 dBm red) – TETRA (415 MHz, -103 dBm blue) coverage comparison (Elmadağ).

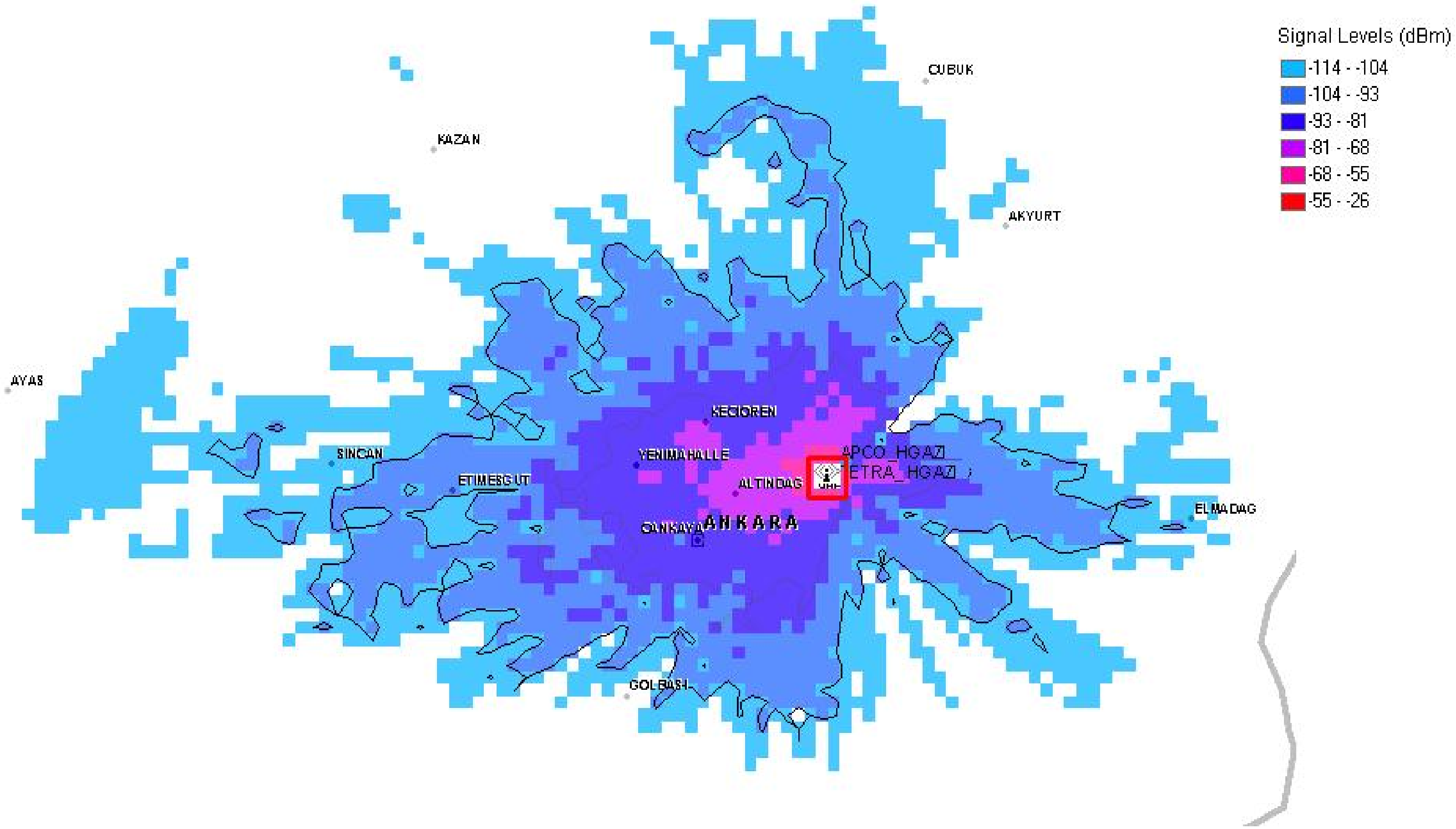

Figure 4-14 APCO25 signal levels (Hüseyingazi, 157 MHz).

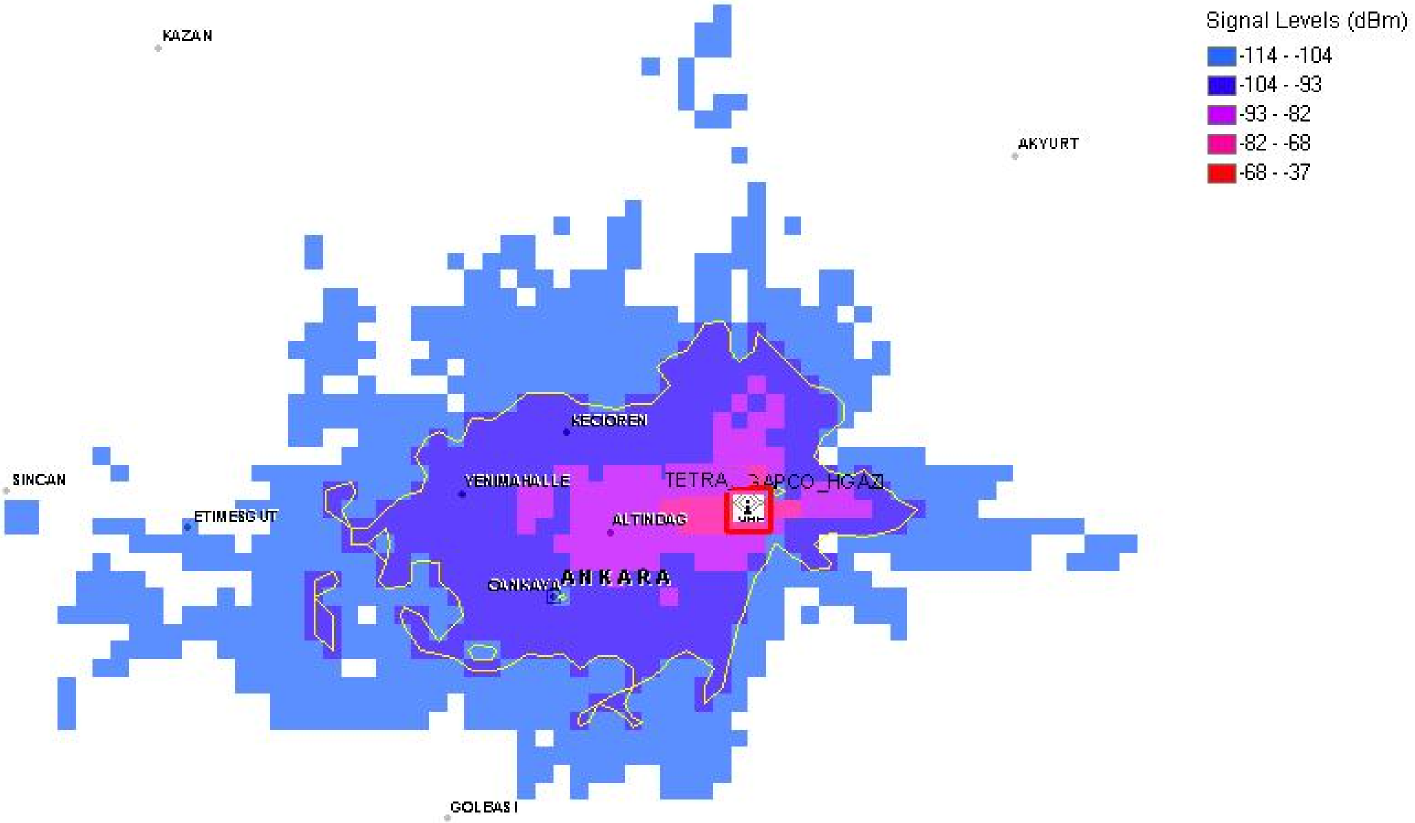

Figure 4-15 TETRA signal levels (Hüseyingazi, 415 MHz).

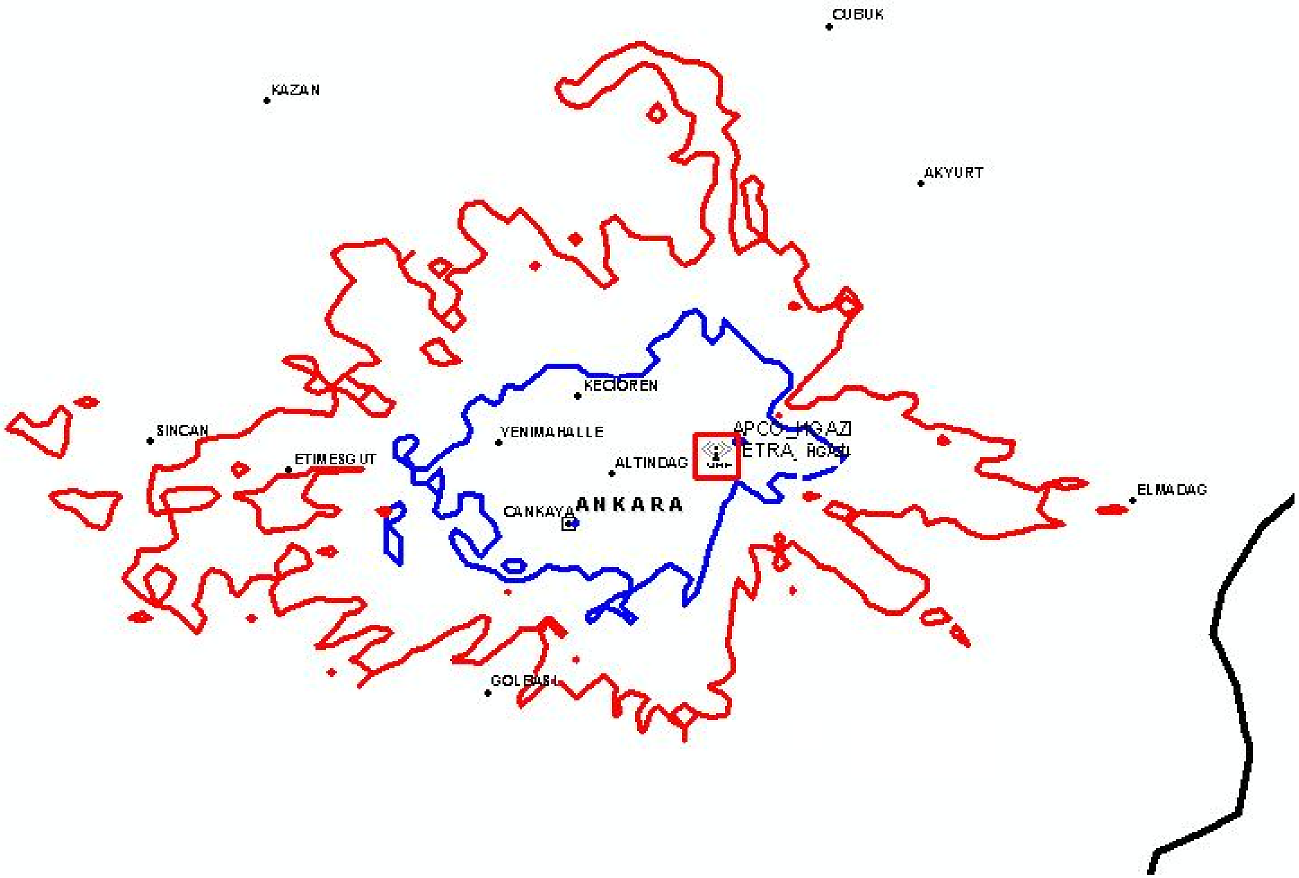

Figure 4-16 APCO25 (157 MHz, -105 dBm red) – TETRA (415 MHz, -103 dBm blue) coverage comparison (Hüseyingazi).

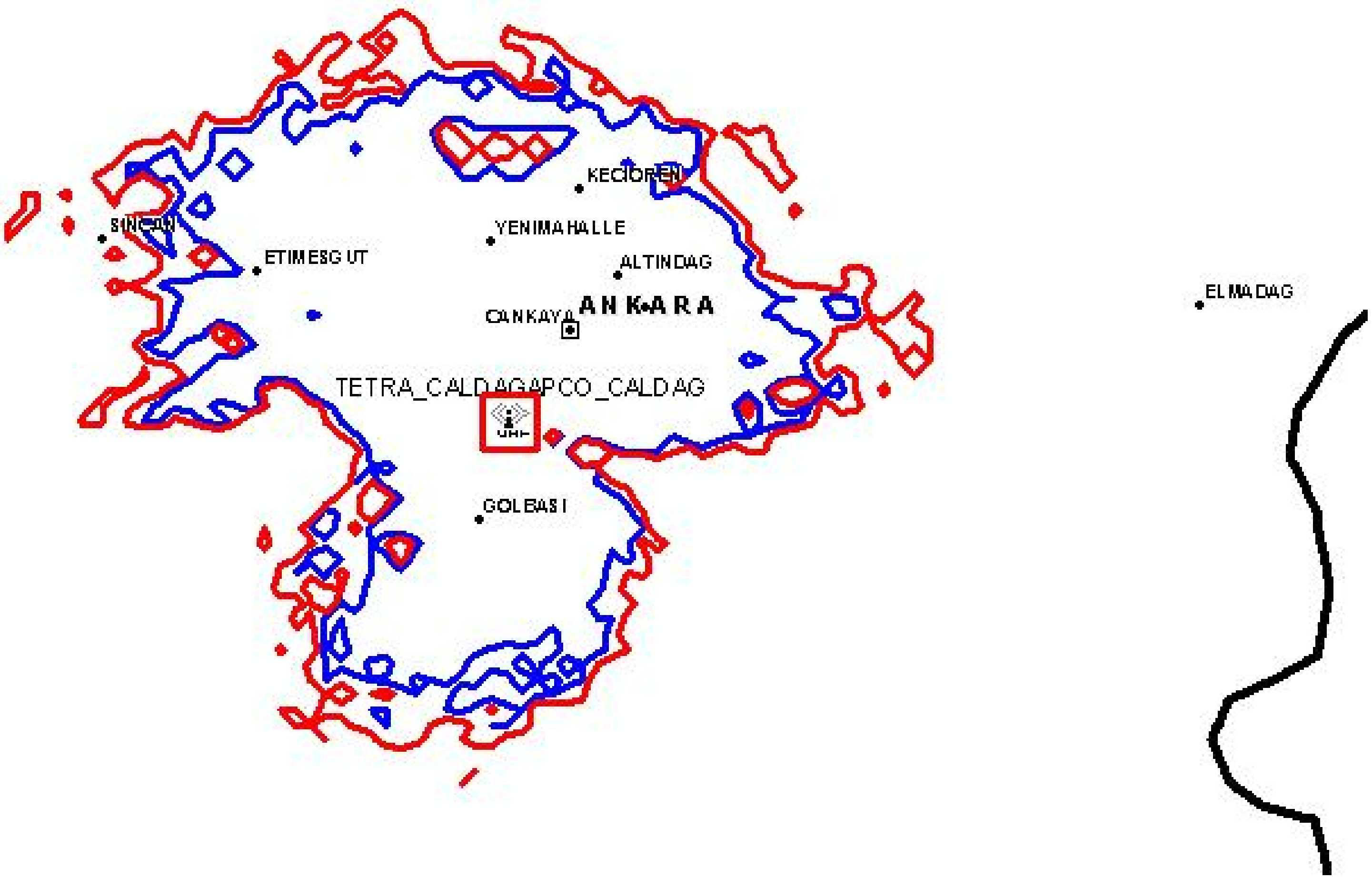

Figure 4-17 APCO25 (415 MHz, -105 dBm red) – TETRA (415 MHz, -103 dBm blue) coverage comparison (Caldağ).

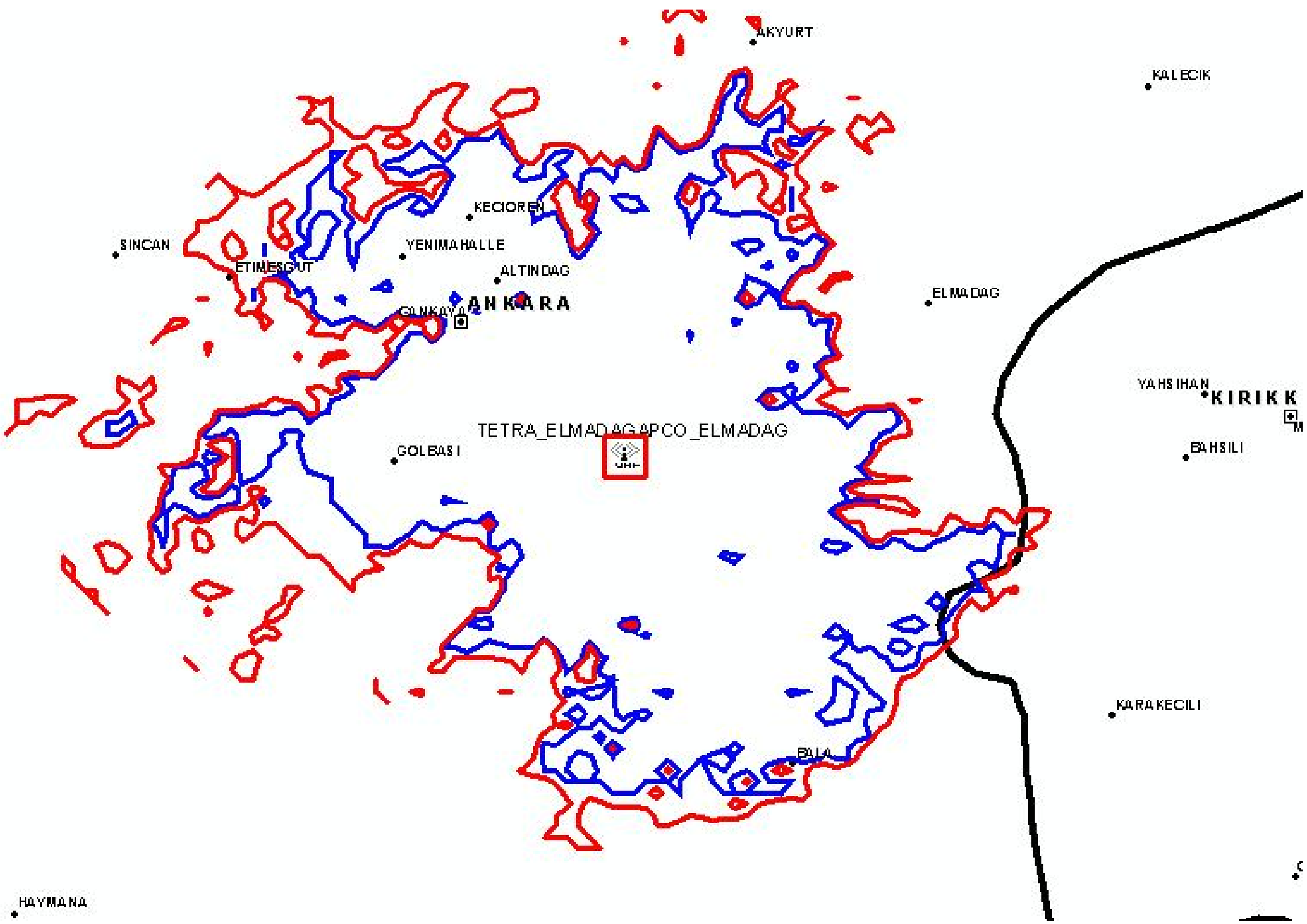

Figure 4-18 APCO25 (415 MHz, -105 dBm red) – TETRA (415 MHz, -103 dBm blue) coverage comparison (Elmadağ).

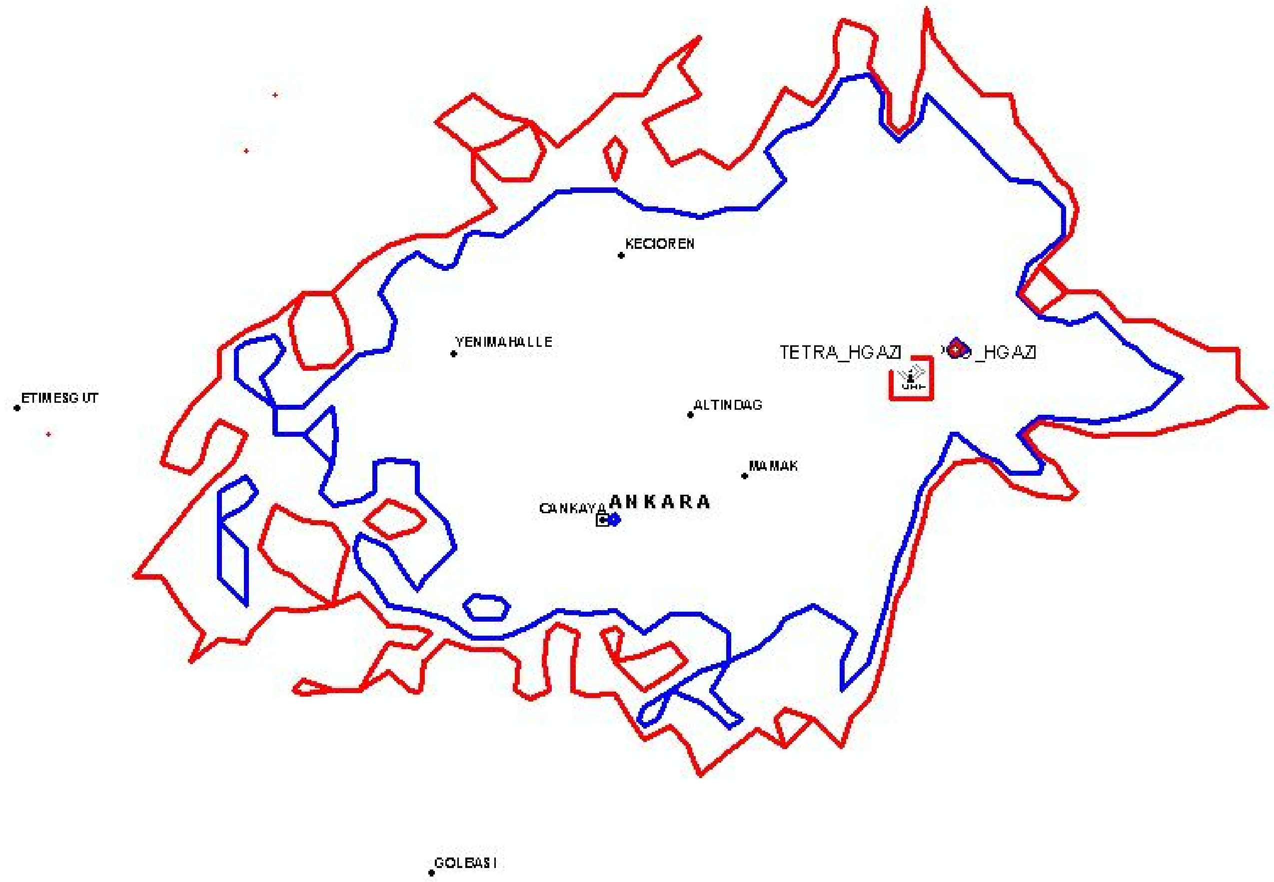

Figure 4-19 APCO25 (415 MHz, -105 dBm red) – TETRA (415 MHz, -103 dBm blue) coverage comparison (Hüseyingazi).

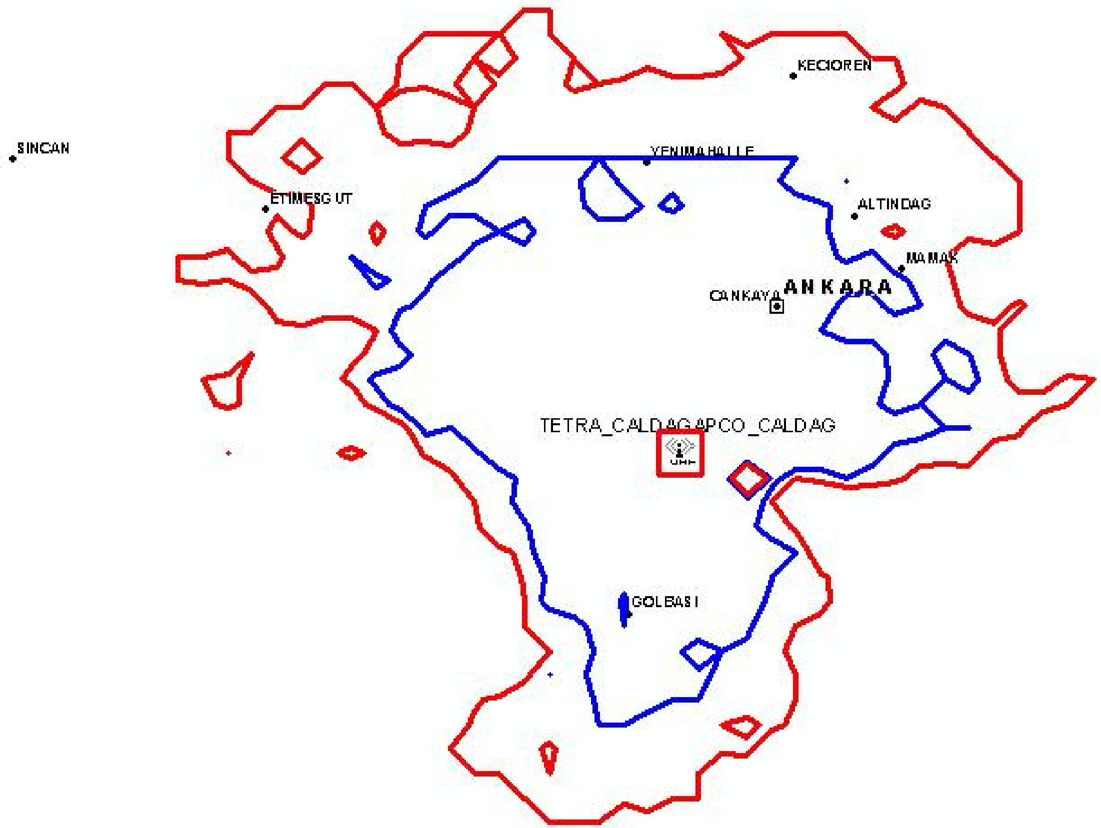

Figure 4-20 APCO25 (780 MHz, -105 dBm red) – TETRA (880 MHz, -103 dBm blue) coverage comparison (Çaldağ).

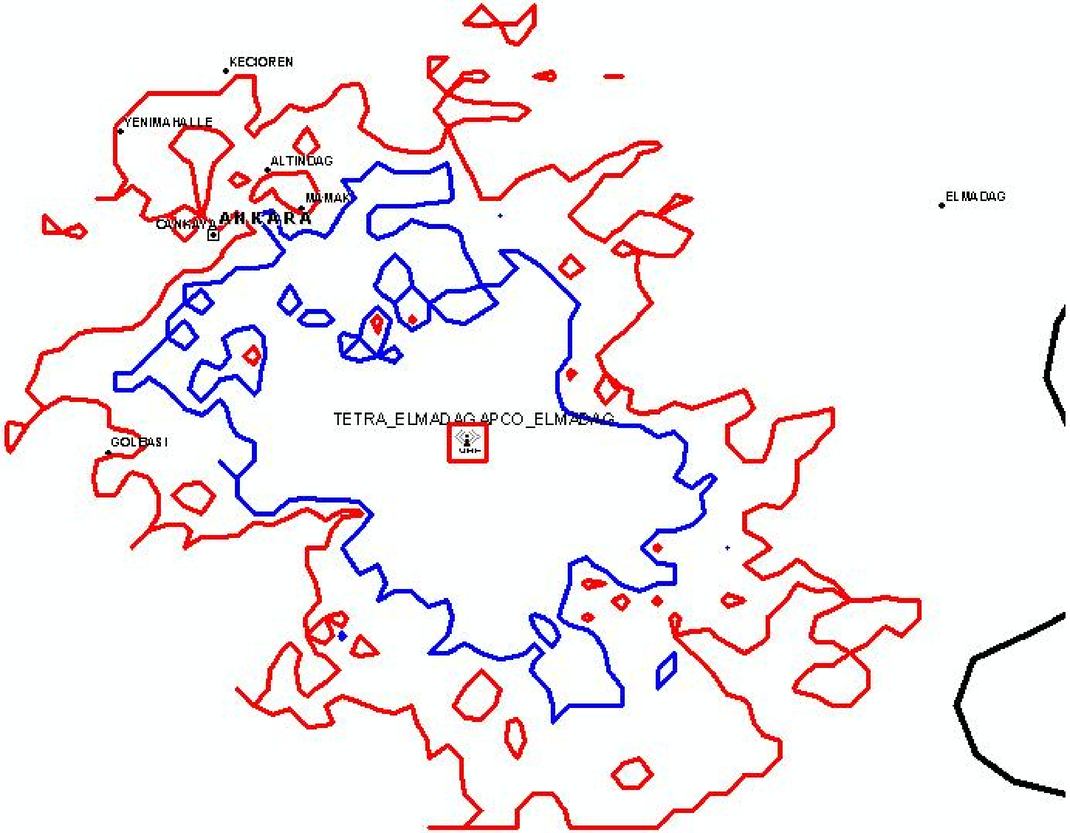

Figure 4-21 APCO25 (780 MHz, -105 dBm red) – TETRA (880 MHz, -103 dBm blue) coverage comparison (Elmadağ).

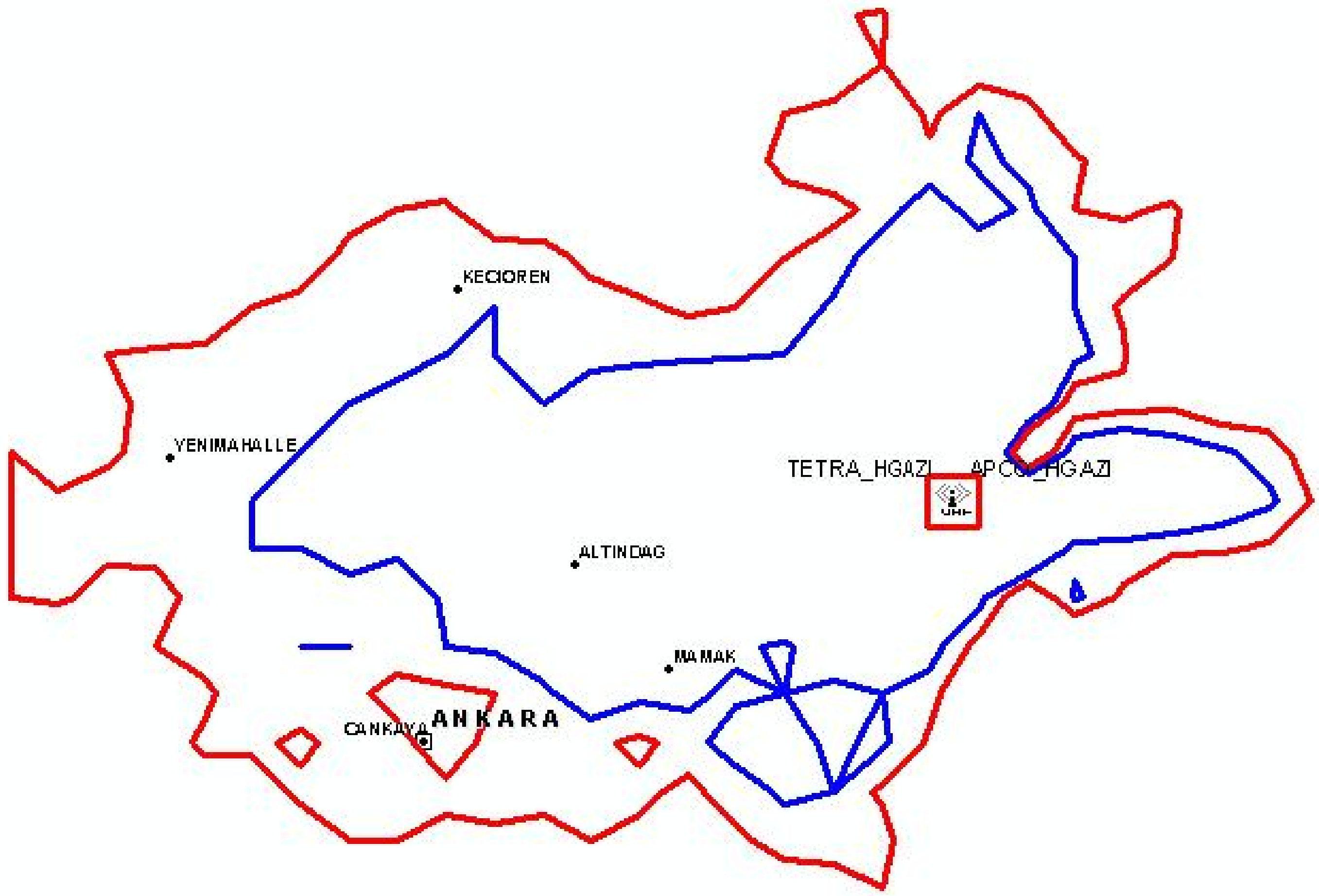

Figure 4-22 APCO25 (780 MHz, -105 dBm red) – TETRA (880 MHz, -103 dBm blue) coverage comparison (Hüseyingazi).

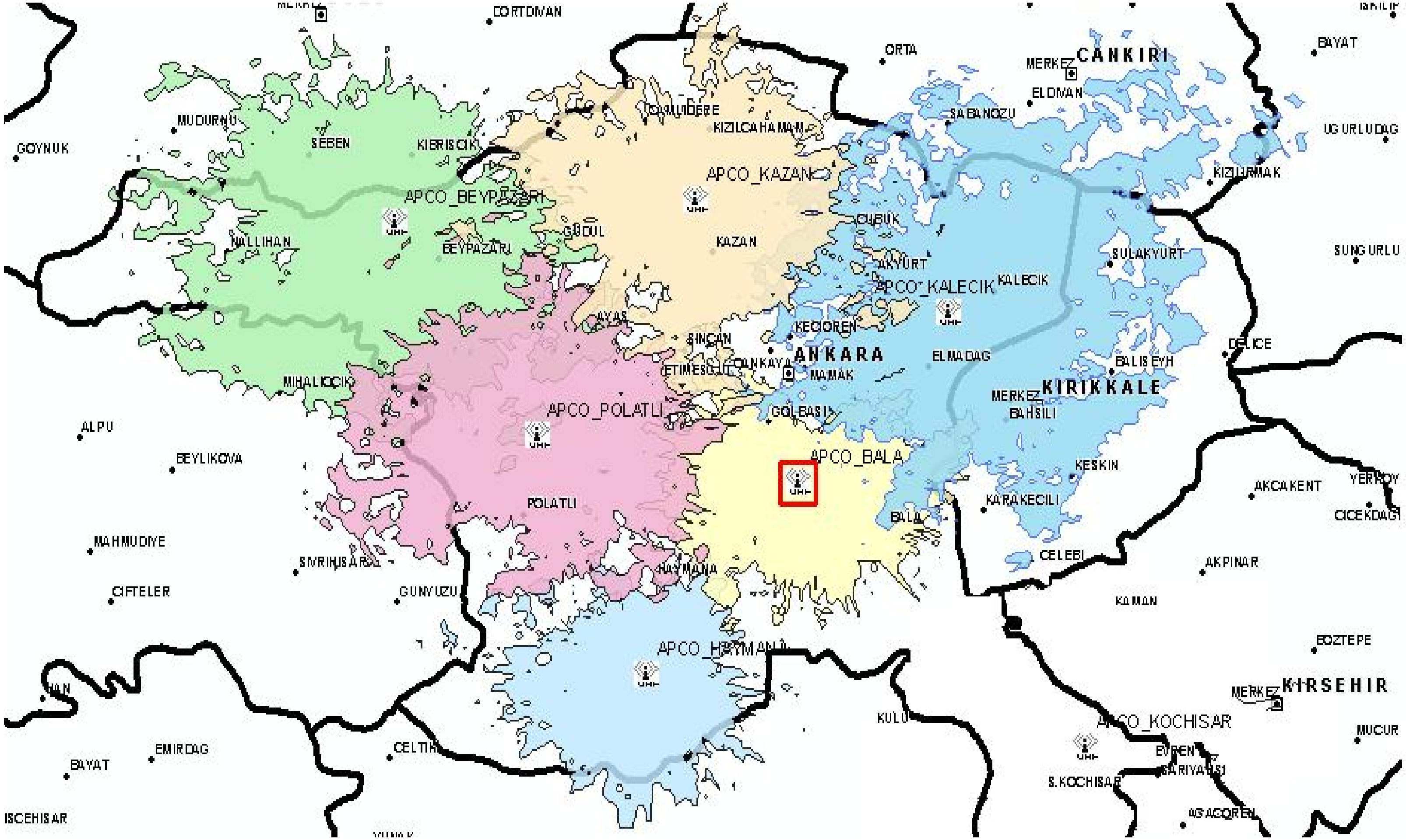

Figure 4-23 Coverage area of Ankara model with six APCO25 stations at 157 MHz (Contour: -105 dBm).

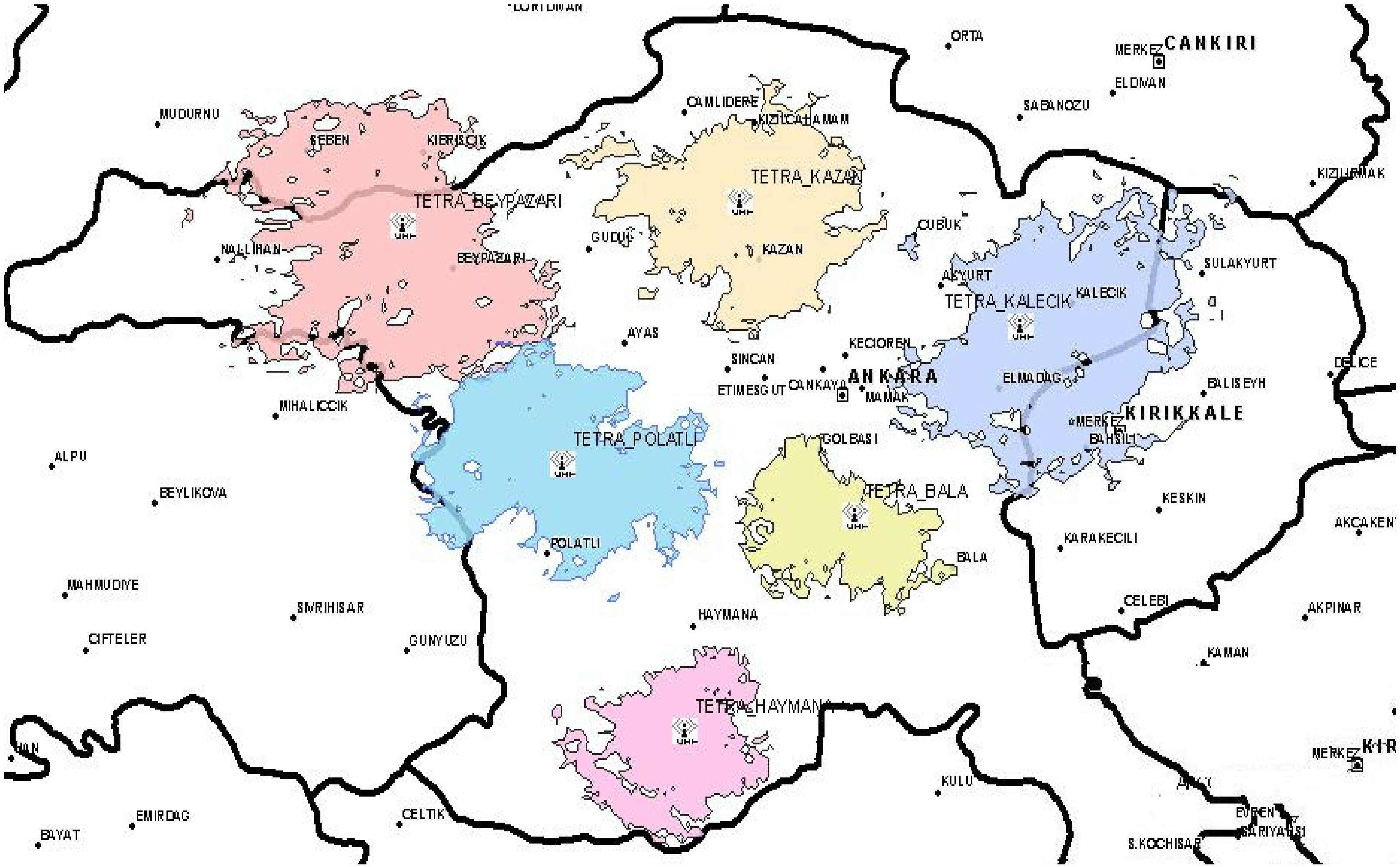

Figure 4-24 Coverage area of Ankara model with six TETRA stations at 415 MHz (Contour: -103 dBm).

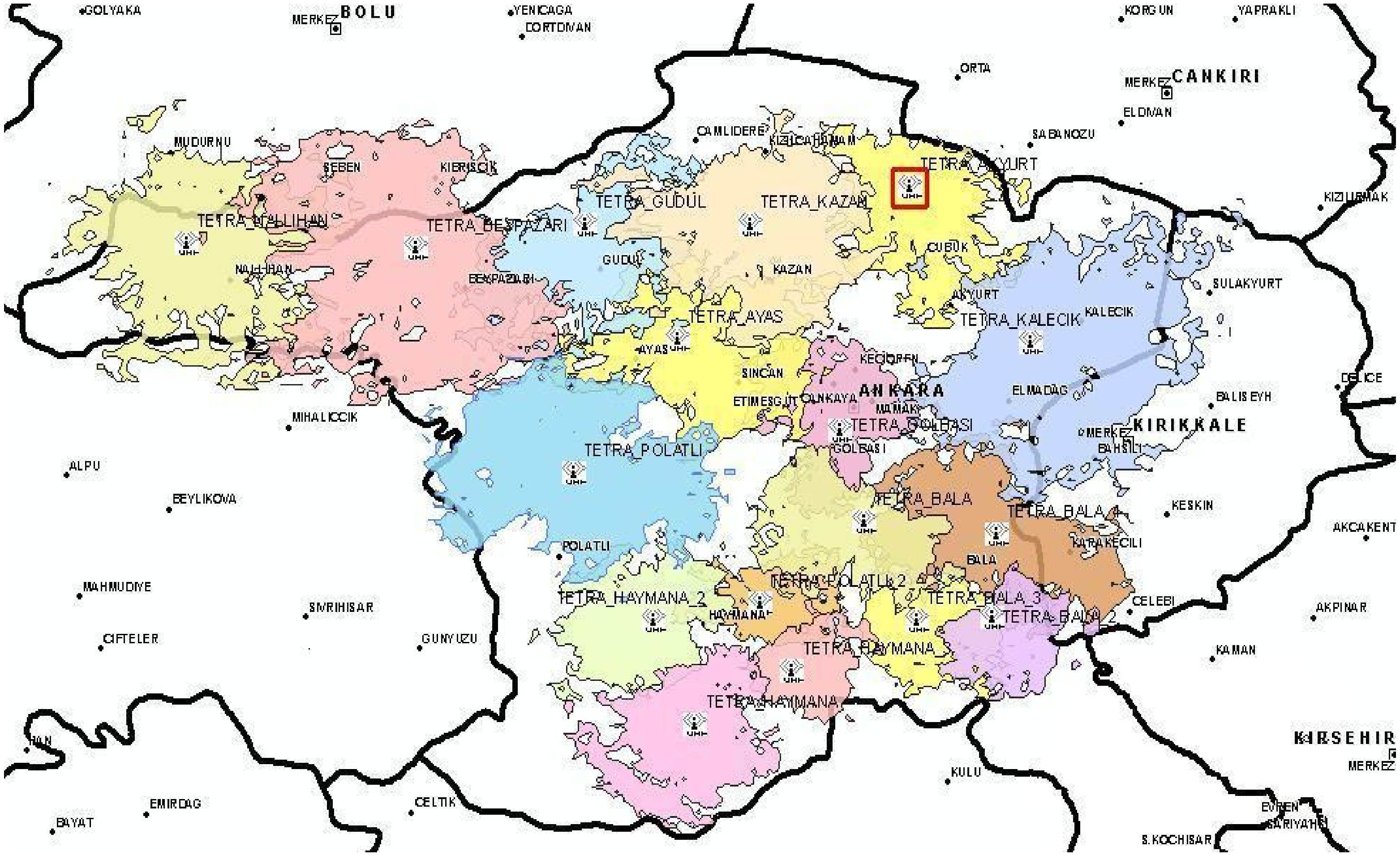

Figure 4-25 Coverage area of Ankara model with seventeen TETRA stations at 415 MHz (Contour: -103 dBm).

CHAPTER 5

RESULTS AND DISCUSSION

In this thesis two important results have been reached. First, the requirement of common communication system for Türkiye is an important issue needs to be considering as soon as possible. Second, although there are some others, two communication systems, namely APCO25 and TETRA, come forward in terms of market sharing. Both systems have their own advantages and disadvantages.

Among the communication system selection criteria, the requirements, the trend of the world or the choices of the developed countries, the overhead costs, and particularly the coverage areas were underlined. Coverage capability of the systems, which has effect on all underlined criteria, has been taken into consideration as a main factor because of the large surface area of Türkiye.

Discussion on Communication System Requirement of Türkiye

Türkiye is faced with so many disasters resulted from natural reasons such as earthquake and flood or social reasons such as terrorism and anarchy because of the situation of the geography surrounding it. The lack of a common communication infrastructure in such a country is not only a handicap but also astonishing.

Fortunately, some studies devoted to this requirement have been carried out over the recent years. However, the studies conducted by province administrations do not cover the whole country. The project intending to set up such a common infrastructure in İstanbul is one of the best examples of these efforts. In the first part of the project, many organizations came together to determine the needs and select the suitable standard. For this reason, a feasibility study was executed by Nippon

Telegraph and Telephone East Corporation firm. Although these efforts are target oriented and well intentioned, they are devoted to solve only the problem of İstanbul. Whereas, when the events and the scenarios given in the first parts of this thesis are considered, it comes out that the solution should be country based, but not province based. Otherwise, in the events where several provinces' emergency personnel are required to work together, the interoperability problems are unavoidable.

On the other hand, Gendarme General Commandership initiates a cellular radio system project covering the whole country. This project is implemented only for the requirements of Gendarme General Commandership. Base stations to be installed will just be used by Turkish Army Forces.

It is possible to increase the number of these examples. The common characteristics of all examples are that all of them solve the problems of a certain province or organization. The public safety common communications infrastructure for the emergency services is an undeniable fact.

The solutions generated for the entire country should have the following specifications.

- Interoperable
- Reliable
- Improvable and expandable
- Feasible
- Secure
- Cost effective

There is no conflict about the specifications among provinces and organizations. The biggest difficulty comes out during the selection of the communication system and the standards because the different organizations serving in different parts of Türkiye have established their own solutions ranging from analog radio systems to GSM networks so far.

Radio system planners may need to conduct a wide range of comparative analyses to determine the type of system that is most appropriate for their environment and requirements. Planners in public safety agencies need to consider, in addition, the special requirements imposed by their mission and operations.

Discussion on Communication System Selection of Türkiye

The selection of the public safety and emergency communications system standards for Türkiye is an important issue. Each standard has its own specifications. However, some principal specifications are almost the same for all standards, so it will be necessary to note some distinguishing factors.

1. The communication type is a key factor. It is seen that the primary communication type of the public safety and emergency services is the voice communications. Certainly, data communications is very beneficial for the solution of many problems. However, when the disasters like an earthquake, an explosion, or a forest fire are taken into consideration, the requirement for voice communications, especially at the first intervention and saving life, comes to front. Therefore, TETRA's advanced data communication capability, is not enough for differing two standards.

2. Another important factor is the preferred applications in the world and choices of the developed countries. At this point two standards, APCO25 and TETRA, are the alternatives. From those, APCO25, as aforementioned, widely used in the USA and other countries in America. A striking matter from our point of wiev is that many countries covering large surface areas use APCO25. Of course this selection is also effected from the USA telecommunication industry. It should not be forgotten that when the countries make such investments, they consider local industrial organizations and tend to use their products. It is not possible to explain the APCO25 support of ANSI and TETRA support of ETSI by only technological superiority.

   TETRA and TETRAPOL, widespread in Europe, are the different versions of the same technology. European Union makes effort to provide agreement on these standards. But, since they are developed by different countries of Europe the agreement becomes a problem. On the other hand, European

Union has decided that the 380-400 MHz band is used by the communications requirements of public safety and emergency services. The efforts related to evacuation of this band are continued. Whereas, this band is also used various countries' Army Forces. NATO countries have not been able to persuade yet to evacuate the whole band.

In summary, when the selections of the countries are considered, it is observed that APCO25 is widely used in America while TETRA is used in Europe. From this perspective, TETRA comes forward since Türkiye is trying to be a part of European Union.

3. All factors above are very important, but not sufficient for the selection of a common communication infrastructure. The installation and operating costs of the systems must also be considered carefully. Cost of the infrastructure is mainly dependent on the number of the base stations to be installed. Each additional station will increase the overhead. The main idea at the development of a cost-effective solution is the usage of small number of base stations having larger coverage areas. Therefore, while evaluating the systems, the coverage areas of them for different geographical conditions and different elevations should also be considered and compared. From this point, in the studies of this thesis, the cost-effectively evaluation has been made by comparing the coverage areas of both standards' COTS products.

In CHAPTER 4, the results of the two groups of coverage analyses implemented for Ankara province are given.

First group of coverage analyses have been implemented for Ankara city center. The aim of these analyses is to compare the coverage areas of APCO25 and TETRA stations one by one. The analyses have been carried out for the COTS products operating in different frequencies. Furthermore, comparison at the same frequency has also been done to avoid misinterpretation.

Second group of analyses has been implemented for the whole province including all towns and villages. The purpose of this study is to compare the number of APCO25 and TETRA base stations required for covering entire province.

According to the results obtained from the analyses,

- Coverage area of a single APCO25 station is larger than that of TETRA when the COTS product parameters are used. According to this, it should be emphasized that APCO25 systems at VHF band cover larger area than TETRA because of low frequency usage advantage. On the other hand, coverage areas would approximately be the same if both systems were in the same frequency.

- When the COTS product parameters are used, ten base stations are necessary to cover entire Ankara province for TETRA, while five base stations are enough for APCO25.

As a result, APCO25 is advantageous in terms of coverage just because of its VHF COTS products. However, using low frequencies may bring some disadvantages as well. It should be noted that the low frequency usage causes an expansion at the size of the hand held radio and its antenna. Certainly, emergency staff avoid from carrying big equipment, which may impede their hard work. Additionally, usage of low frequencies may result in deviation from European Union standards necessary for interoperability. This may be an important issue for Türkiye as a nominated member.

The backward compatibility should also be considered in the context of the cost-effectiveness of a communication system. In Türkiye, most of the organizations participated in public safety and emergency services use conventional systems for communication. Therefore, it will be very expensive to replace their conventional systems by modern systems abruptly. This replacement should be done gradually. Hence, the backward compatibility of APCO25 makes it advantageous over TETRA. However, it should not be discarded that the handset prices of APCO25 (around 4000 – 5000 USD) are higher than TETRA (around 500 – 1000 USD).

When it is considered that the basic requirement of public safety and emergency organizations is mainly voice communications rather than data and the coverage area of this kind of communication systems should include the rural regions in addition to urban, the selection of the lower frequencies will provide cost-effective solution to the problem. However, at this point, frequency requirement appears as an important criterion which should be evaluated. As mentioned before VHF band is an open band for civil applications. May be, it is the most intensively used part of the spectrum. Public safety and emergency services have lots of different user groups. In addition to communication requirement among the members of a group, groups may need to communicate to each other. The increment of the number of groups and group members will also increase the number of communication channels. Of course, the natural result of this is the augmentation in frequency demand.

The most striking advantage of TETRA is the efficient usage of spectrum by fitting four traffic channels in a 25 kHz band using TDMA technology. APCO25 allows only two traffic channels yet in the same band. But, they claim that the number of channels will be increased to four at the completion of Phase 2 studies of APCO25 (see Figure 3-14).

The full-duplex capability of TETRA makes it easy to use. APCO25 does not operate in full-duplex mode.

The successful multi-vendor approach (encouraging tens of manufacturers) of TETRA, makes the improvements faster, the product support better, and the product prices lower.

The IP applications are supported and provided by TETRA more efficiently than APCO25 by means of its advanced data communications capability. From the data communications aspect TETRA's superiority is evident due to its higher transmission rates (up to 28.8 kbps) and advanced multi-vendor data communications infrastructure.

Conclusions

While searching for the solution to the public safety and emergency communications problem of Türkiye the following questions should be answered. Although these questions have already been answered so far, they are given again as a whole here to summarize the discussion and make the solution investigation easy.

- What are the geographical characteristics of Türkiye? Has it large surface area, big mountains, rough regions, large plains?

  - Yes, Türkiye has a large surface area (780 576 km^2) and its geographical characteristics show great differences from region to region. While some parts of Türkiye include large flat areas, the others include high mountains and hills.

- Are the crowded regions of Türkiye under high natural or social disaster risk?

  - Yes, the crowded cities of Turkey such as İstanbul and Ankara are under natural or social disaster risk. The earthquake risk in İstanbul can be given as the most striking example to this question.

- What kinds of communication systems are widely used by public safety and emergency organizations of Türkiye?

  - Conventional VHF/FM analog radio systems are widely used by such organizations.

- What kind of communication has the priority for public safety and emergency communications? Voice or data?

  - Voice communications always have the priority for public safety and emergency.

- Will the communication system to be installed include the rural and suburban areas?

  - Yes, since the natural and social disaster risk map of Türkiye covers the rural and suburban areas it is unavoidable to extend the scope of the communication system.

When the answers above are investigated the following conditional solutions for the public safety and emergency communications problem of Türkiye are reached.

- When the geographical characteristics of Türkiye are considered APCO25 is seen as the best solution since its large coverage characteristics (see CHAPTER 4).

- Since the traffic channels requirement will increase considerably by population, for the crowded regions TETRA seem much more advantageous solution to the problem because it fits higher number of channels in 25 kHz band. However, if APCO25 Phase 2 studies, on increasing number of channels, give successful results, none of the systems is superior to the other from this aspect.

- The backward compatibility of APCO25 makes it advantageous over TETRA. When it is thought that the conventional radio systems are widely used in Türkiye the backward compatibility will decrease initial cost considerably.

- Although the voice communications has the priority in public safety and emergency communications, the developing technology especially in the internet area will make the use of data communications unavoidable. From this point of view TETRA is more advantageous than APCO25 since it provides higher spectral efficiency and data transmission rates.

- Another important subject is the integration to the European Union. It is obvious that the solution is TETRA in this case.

Although all of the results above give some ideas about the public safety communications system selection of Türkiye, an exact solution has not been proposed yet in the text. For this reason, a technology selection model explained in [5] is adopted and modified according to the requirements of our problem. The model is based on the selection of the most suitable technology by assigning proper weights to the *technical* and *commercial* specifications of the alternatives. In our case, considering the factors affecting calculations, the specifications are categorized as *quantitative* and *qualitative*. These quantitative and qualitative specifications are listed below in alphabetical order.

Quantitative Specifications:

- Base station output power
- Base station receiver sensitivity
- Handset price
- Maksimum data rate
- Market sharing percentage
- Mean cell radius
- Number of channels per 25 kHz

Qualitative Specifications:

- Backward compatibility
- COTS products in the VHF band
- Coverage characteristics
- Data communication capabilities
- European Union support
- Modes of operation
- Product support

According to [5], the technology selection can be done with the following procedure:

Assuming that "*r*" candidates are under examination and comparison; and that there are "*n*" quantitative specifications and "*m*" qualitative specifications for each candidate; then for every candidate and for each one of its quantitative specifications $QNT_{i,k}$ $(i = 1,...,n \text{ and } k = 1,...,r)$, a quantitative coefficient $CQNT_{i,k}$ is calculated as follows:

$$CQNT_{i,k} = \frac{QNT_{i,k}}{QNT_{i,\max}} 100 \quad \text{for } i = 1,...,n \text{ and } k = 1,...,r \tag{5-1}$$

where, $QNT_{i,k}$ is the quantitative specification *i* for the candidate *k*; $CQNT_{i,k}$ is the quantitative coefficient *i* for the candidate *k*; and $QNT_{i,\max}$ is the largest quantitative coefficient, i.e. $QNT_{i,\max} \geq QNT_{i,k}$ for all *k*.

Similarly, for every candidate under examination and for each one of its qualitative specifications $QLT_{j,k}$ $(j = 1,...,m \text{ and } k = 1,...,r)$, a qualitative coefficient $CQLT_{j,k}$ is calculated as follows:

$$CQLT_{j,k} = \frac{QLT_{j,k}}{QLT_{j,\max}}100 \quad \text{for } j = 1,...,m \text{ and } k = 1,...,r \tag{5-2}$$

where, $QLT_{j,k}$ is the qualitative specification *j* for the candidate *k*; $CQL_{j,k}$ is the qualitative coefficient *j* for the candidate *k*; and $QLT_{j,\max}$ is the largest qualitative coefficient, i.e. $QLT_{j,\max} \geq QLT_{j,k}$ for all *k*.

Obviously, certain specifications correspond to coefficients that could be calculated relative to the minimum value and not the maximum one. In such a case, in (5-1) and (5-2) $QNT_{i,\min}$ and $QLT_{j,\min}$ should be used instead of $QNT_{i,\max}$ and $QLT_{j,\max}$ respectively, but in reverse order, i.e. $QNT_{i,\min}$ and $QLT_{j,\min}$ in the numerator.

Anyhow, in both cases, the function of these quantitative and qualitative coefficients is for the *normalization* of the corresponding specifications, which means to convert them in a unitless form. This is being achieved by expressing them relative to the best one (max or min) of each specification.

Afterwards, for every candidate k $(k = 1,...,r)$ under examination, a quantitative and a qualitative grade are calculated as follows:

$$GQNT_k = \sum_{i=1}^{n} x_i CQNT_{i,k} \quad \text{for } k \ (k = 1,...,r) \tag{5-3}$$

where, $GQNT_k$ is the quantitative grade of the candidate *k*; and x_i is the *weighing* factor of the quantitative specification *i*, $0 < x_i < 1$ for $i = 1,...,n$ and $\sum_{i=1}^{n} x_i = 1$.

$$GQLT_k = \sum_{j=1}^{n} y_j CQLT_{j,k} \quad \text{for } k \ (k = 1,...,r) \tag{5-4}$$

where, $GQLT_k$ is the qualitative grade of the candidate *k*; and y_j is the *weighing* factor of the qualitative specification *j*, $0 < y_j < 1$ for $j = 1,...,m$ and $\sum_{j=1}^{m} y_j = 1$.

Finally, for each candidate its relative price is calculated, as follows:

$$R_k = \frac{P_k}{w_{GQNT} GQNT_k + w_{GQLT} GQLT_k} \quad \text{for } k = 1,...,r \tag{5-5}$$

where R_k is the relative price of the candidate *k*, P_k is the actual price of the candidate *k*, and w_{GQNT}, w_{GQLT} are the weighing factors of the quantitative and the qualitative grade respectively: $0 < w_{GQNT} < 1$, $0 < w_{GQLT} < 1$, $w_{GQNT} + w_{GQLT} = 1$.

According to the model, the best candidate is the one which has the lowest relative price R_k.

In our case, the selection model has been applied for two alternative communication system standards APCO25 and TETRA, i.e. $r = 2$. The number of criteria for making the screening and the selection are 14. From them, 7 are based on quantitative specifications (n = 7) and 7 are based on qualitative ones (m = 7) and they are presented in Table 5-1 and Table 5-2 respectively together with their corresponding weighing factors (x_i and y_j).

It should also be noted here that the specifications and related weighing factors are selected subjectively.

Table 5-1 Quantitative specifications and their weighing factors.

i	**Quantitative Specification**	**APCO25**	**TETRA**	x_i
1	Base station output power	100 W	30 W	0.15
2	Base station receiver sensitivity	-105 dBm	-103 dBm	0.15
3	Handset price	4500 USD	800 USD	0.05
4	Maksimum data rate	9.6 kbps	28.8 kbps	0.15
5	Market sharing percentage	32 %	48 %	0.05
6	Mean coverage distance	30 km	20 km	0.25
7	Number of channels per 25 kHz	2	4	0.20

Table 5-2 Qualitative specifications and their weighing factors.

j	**Qualitative Specification**	**APCO25**	**TETRA**	y_j
1	Backward compatibility	Yes	No	0.15
2	COTS products in the VHF band	Yes	No	0.20
3	Coverage characteristics	Very good	Reasonable	0.20
4	Data communication capabilities	Good	Better	0.20
5	European Union support	No	Yes	0.15
6	Modes of operation	Half Duplex	Half & Full Duplex	0.05
7	Product support	Good	Better	0.05

Since both quantitative and qualitative specifications are extensively important for our case, w_{GQNT} and w_{GQLT} have been selected as 0.5.

Thus, according to Eqs. (5-1) and (5-2), Table 5-1 and 5-2 with the quantitative specifications $QNT_{i,k}$ and the qualitative specifications $QLT_{i,k}$ and their weighing factors, the quantitative and the qualitative coefficients $CQNT_{i,k}$ and $CQLT_{i,k}$ are calculated as in (Tables 5 and 6).

Table 5-3 Quantitative coefficients.

Candidate	$CQNT_{1,k}$	$CQNT_{2,k}$	$CQNT_{3,k}$	$CQNT_{4,k}$	$CQNT_{5,k}$	$CQNT_{6,k}$	$CQNT_{7,k}$
APCO25	100.00	100.00	17.78	33.33	66.67	100.00	50.00
TETRA	30.00	98.10	100.00	100.00	100.00	66.67	100.00

Table 5-4 Qualitative coefficients.

Candidate	$CQLT_{1,k}$	$CQLT_{2,k}$	$CQLT_{3,k}$	$CQLT_{4,k}$	$CQLT_{5,k}$	$CQLT_{6,k}$	$CQLT_{7,k}$
APCO25	100.00	100.00	100.00	80.00	0.00	80.00	80.00
TETRA	0.00	0.00	40.00	100.00	100.00	100.00	100.00

Quantitative and qualitative grades are calculated according to Table 5-3 and Table 5-4 and Eqs. (5-3) and (5-4).

Table 5-5 Quantitative/Qualitative grades and relative prices.

Candidate	$GQNT_k$	$GQLT_k$	$w_{GQNT}GQNT_k + w_{GQLT}GQLT_k$	R_k
APCO25	74.22	80.48	77.35	1.29
TETRA	79.00	53.00	66.00	1.51

When the results given in Table 5-5 are investigated, the best option among the alternatives is APCO25 which has lower relative price R_k. This result has been reached by assuming that the actual prices (P_k) of both systems are equal to 100 units. When it is considered that the actual price of TETRA is more expensive than APCO25 because of the larger number of base station requirement, the result given above is further verified.

As a final result, the public safety and emergency communication problem of Türkiye should be solved without losing time and money. To do this, considering the realities of our country, a comprehensive, permanent, and low-cost solution should be adopted. When the problem is examined based on a technology selection model, among two alternatives, APCO25 comes to front. Although TETRA has some important advantages, APCO25 is considered to be more suitable for Türkiye especially for two reasons: Large coverage characteristics and compatibility with available infrastructures.

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